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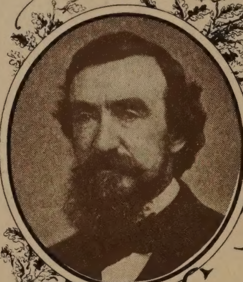

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THE MANUFACTURE
OF
PULP AND PAPER

VOLUME IV

Pulp and Paper Manufacture

IN FIVE VOLUMES

An Official Work Prepared
under the direction of the

Joint Executive Committee of the
Vocational Education Committees of the
Pulp and Paper Industry of the
United States and Canada

VOL. I—MATHEMATICS, HOW TO READ DRAWINGS, PHYSICS.

II—MECHANICS AND HYDRAULICS, ELECTRICITY, CHEMISTRY.

III—PREPARATION OF PULP.

IV, V—MANUFACTURE OF PAPER.

THE MANUFACTURE OF PULP AND PAPER

A TEXTBOOK OF MODERN PULP AND PAPER MILL PRACTICE

Prepared Under the Direction of the Joint Executive Committee on Vocational Education Representing the Pulp and Paper Industry of the United States and Canada

VOLUME IV

PREPARATION OF RAGS AND OTHER FIBERS; TREATMENT OF WASTE PAPERS; BEATING AND REFINING; LOADING AND ENGINE SIZING; COLORING; GENERAL MILL EQUIPMENT

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SECOND EDITION

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PREFACE TO THE SECOND EDITION

It is not often that the revision of a book entails such a complete overhauling as has been given to Volumes IV and V of *Manufacture of Pulp and Paper* during the preparation of this, the second, edition. The volume preceding these, which deals with the manufacture and treatment of wood pulp, was revised and enlarged in 1927. The two succeeding volumes, which deal with the manufacture and testing of papers, may be considered as two parts of one subject, and this has been taken advantage of in rearranging them somewhat, so that the entire subject of paper machines has been included in the latter volume. This necessitated the transfer of the Section on General Mill Equipment to Vol. IV.

One Section, *Coated Papers*, has been entirely rewritten. The subject of *Engine* (rosin) *Sizing* has also been rewritten, and an appendix has been prepared covering *Hydrogen-Ion Concentration.* Other Sections have been revised and brought up to date, and two entirely new subjects—*The Generation and Use of Steam* and *Paper-Making Details*—have been added.

At no time in the history of the pulp and paper industry has there been more activity in scientific and engineering research. A number of projects are now in the stage of trial and development, and these may result in quite radical changes in processes of pulp and paper making. The editor will appreciate receiving any suggestions tending toward the improvement of the present text.

J. N. Stephenson,
Editor.

Gardenvale, Quebec
July, 1928.

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PREFACE TO THE FIRST EDITION

In numerous communities where night schools and extension classes have been started or planned, or where men wished to study privately, there has been difficulty in finding suitable textbooks. No books were available in English, which brought together the fundamental subjects of mathematics and elementary science and the principles and practice of pulp and paper manufacture. Books that treated of the processes employed in this industry were too technical, too general, out of date, or so descriptive of European machinery and practice as to be unsuitable for use on this Continent. Furthermore, a textbook was required that would supply the need of the man who must study at home because he could not or would not attend classes.

Successful men are constantly studying; and it is only by studying that they continue to be successful. There are many men, from acid maker and reel-boy to superintendent and manager, who want to learn more about the industry that gives them a livelihood, and by study to fit themselves for promotion and increased earning power. Pulp and paper makers want to understand the work they are doing—the how and why of all the various processes. Most operations in this industry are, to some degree, technical, being essentially either mechanical or chemical. It is necessary, therefore, that the person who aspires to understand these processes should obtain a knowledge of the underlying laws of Nature through the study of the elementary sciences and mathematics, and be trained to reason clearly and logically.

After considerable study of the situation by the Committee on Education for the Technical Section of the Canadian Pulp and Paper Association and the Committee on Vocational Education for the Technical Association of the (U. S.) Pulp and Paper Industry, a joint meeting of these committees was held in Buffalo

in September, 1918, and a Joint Executive Committee was appointed to proceed with plans for the preparation of the text, its publication, and the distribution of the books. The scope of the work was defined at this meeting, when it was decided to provide for preliminary instruction in fundamental Mathematics and Elementary Science, as well as in the manufacturing operations involved in modern pulp and paper mill practice.

The Joint Executive Committee then chose an Editor, Associate Editor, and Editorial Advisor, and directed the Editor to organize a staff of authors consisting of the best available men in their special lines, each to contribute a section dealing with his specialty. A general outline, with an estimated budget, was presented at the annual meetings in January and February, 1919, of the Canadian Pulp and Paper Association, the Technical Association of the Pulp and Paper Industry, and the American Paper and Pulp Association. It received the unanimous approval and hearty support of all; and the budget asked was raised by an appropriation of the Canadian Pulp and Paper Association and contributions from paper and pulp manufacturers and allied industries in the United States, through the efforts of the Technical Association of the Pulp and Paper Industry.

To prepare and publish such a work is a large undertaking; its successful accomplishment is unique, as evidenced by these volumes, in that it represents the cooperative effort of the Pulp and Paper Industry of a whole Continent.

The work is conveniently divided into sections, and bound into volumes for reference purposes; it is also available in pamphlet form for the benefit of students who wish to master one part at a time, and for convenience in the class room. This latter arrangement makes it very easy to select special courses of study; for instance, the man who is specially interested, say, in the manufacture of pulp or in the coloring of paper or in any other special feature of the industry, can select and study the special pamphlets bearing on those subjects and need not study others not relating particularly to the subject in which he is interested, unless he so desires. The scope of the work enables the man with but little education to study in the most efficient manner the preliminary subjects that are necessary to a thorough understanding of the principles involved in the manufacturing processes and operations; these subjects also afford an excellent review and reference textbook to others. The work

is thus especially adapted to the class room, to home study, and for use as a reference book.

It is expected that universities and other educational agencies will institute correspondence and class-room instruction in Pulp and Paper Technology and Practice with the aid of these volumes. The aim of the Committee is to bring an adequate opportunity for education in his vocation within the reach of every one in the industry. To have a vocational education means to be familiar with the past accomplishments of one's trade, and to be able to pass on a record of present experience for the benefit of those who will follow.

To obtain the best results, the text must be diligently studied; a few hours of earnest application each week will be well repaid through increased earning power and added interest in the daily work of the mill. To understand a process fully, as in making acid or sizing paper, is like having a light turned on when one has been working in the dark. As a help to the student, many practical examples for practice and study and review questions have been incorporated in the text; these should be conscientiously answered.

This volume deals with the manufacture of paper in the same authoritative and comprehensive manner as the subject of the manufacture of pulp was covered in a preceding volume. In spite of the antiquity of the paper industry, recent developements have been remarkable. There is still almost unlimited opportunity for exhaustive improvement in equipment and operation, and further advances will result from the study of what has already been accomplished. The progress that has been made in paper manufacture is expressed in the carefully prepared and exceptionally well illustrated text of this volume and the volume that follows. The importance of paper—its place as an absolute necessity in civilized life—is now fully recognized; and every one should be interested in and be able to understand the descriptions herein given of the processes and equipment involved in its manufacture. Never have such care and expense been devoted to the preparation of an industrial textbook.

A feature of this series of volumes is the wealth of illustrations, which are accompanied by detailed descriptions of typical apparatus. In order to bring out a basic principle, it has been necessary, in some cases, slightly to alter the maker's drawing,

and exact scales have not been adhered to. Since the textbook is in no sense a "machinery catalog," maker's names have been mentioned only when they form a necessary descriptive item. Much of the apparatus illustrated and many of the processes described are covered by patents, and warning is hereby given that patent infringements are costly and troublesome.

A valuable feature of this work, which distinguishes it from all others in this field, is that each Section was examined and criticised while in manuscript by several competent authorities; in fact, this textbook is really the work of more than one hundred men who are prominent in the pulp and paper industry. Without their generous assistance, often at personal sacrifice, the work could not have been accomplished. Even as it stands, there are, no doubt, features that still could be improved. The Committee, therefore, welcomes helpful criticisms and suggestions that will assist in making future editions of still greater service to all who are interested in the pulp and paper industry.

The Editor extends his sincere thanks to the Committee and others, who have been a constant support and a source of inspiration and encouragement; he desires especially to mention Mr. George Carruthers, Chairman, and Mr. R. S. Kellogg, Secretary, of the Joint Executive Committee; Mr. J. J. Clark, Associate Editor and Mr. T. J. Foster, Editorial Advisor.

The Committee and the Editor have been generously assisted on every hand; busy men have written and reviewed manuscript, and equipment firms have contributed drawings of great value and have freely given helpful service and advice. Among these kind and generous friends of the enterprise are: Mr. G. R. Alden, Mr. M. J. Argy, Mr. O. Bache-Wiig, Mr. James Beveridge, Mr. J. Brooks Beveridge, Mr. A. O. Bragg, Mr. H. P. Carruth, Mr. T. L. Crossley, Mr. Martin L. Griffin, Mr. Hammill, Mr. H. R. Harrigan, Mr. T. Imbleau, Miss H. U. Kielly, Mr. Kenneth T. King, Mr. W. G. MacNaughton, Mr. J. O. Mason, Miss J. E. Minor, Mr. Maurice Neilson, Mr. V. E. Nunez, Mr. Elis Olsson, Mr. C. E. Planck, Mr. J. S. Riddile, Mr. A. A. Scott, Mr. George K. Spence, Mr. Edwin Sutermeister, Mr. S. D. Wells, Mr. F. G. Wheeler, and Bird Machine Co., Brunswick-Kroeschel Co., Canadian Ingersoll-Rand Co., Claflin Engineering Co., Dilts Machine Works, Dominion Engineering Works, E. I. Dupont de Nemours Co., General Electric Co., Wm. Hamilton Co., Harland Engineering Co., F. C. Huyck & Sons, Hydraulic Machinery Co.,

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J. Newell Stephenson,
Editor

For the
Joint Executive Committee on Vocational Education,
George Carruthers, *Chairman*, R. S. Kellogg, *Secretary*,
T. L. Crossley, R. S. Hatch, G. E. Williamson.

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SECTION 1

PREPARATION OF RAG AND OTHER FIBERS

By E. C. Tucker, A. B.

RAGS AND RAG FIBERS

INTRODUCTION

1. A Brief History of the Use of Rags in Paper Making.—The earliest human records were made on stone; in some countries scratched or chiseled, in others written with chalk or colored ore. Other and more convenient substances used later in various places were, pieces of wood—as bamboo, bark, leaves—and prepared skins, as parchment and vellum. At a very early date, the Egyptians prepared a writing material from papyrus, a tall reed growing in the Nile, and called it also *papyrus*, whence our word **paper**. It was made by peeling off the layers of the stem, laying the long ones side by side until a strip of the desired width was obtained, then crossing them with short pieces. The sap served as an adhesive; and, after drying in the sun, the papyrus could be rubbed to a surface that could be written on with ink.

A shortage of papyrus in Asia Minor resulted in the invention of *parchment*, a specially dried calf or goat skin, filled by rubbing in chalk. Because of a similar famine in Rome, *boards*, covered with wax, were used; they were written on with a sharp instrument called a *stylus*. Several layers of wax were sometimes put on the same tablet.

2. The early Greeks wrote letters, notes, mortgages, etc. on broken pieces of pottery. The Chaldeans and Syrians wrote their records in soft clay bricks, which were then baked. Librarians must have used wheelbarrows!

The Chinese were the first real pulp and paper makers. They soaked pieces of bamboo in pits of lime water and separated the fibers by pounding. Rag and other fibers were also used, the process of making the paper being essentially the same as in use now in making hand-made papers.

3. At the dawn of the Christian era, paper making from rag fibers was a well-established art in China. From there the secrets of the process spread westward, and were carried to Europe by the invasions of the barbaric tribes. During the middle ages, the process was improved and developed, and by the end of the fourteenth century it was firmly established throughout southern Europe.

In England, the development was very slow, for it was not until three centuries later that the industry took firm hold there. As would be expected, the delay with which the industry was developed in England was further reflected in this country, and it was not until the last half of the eighteenth century that paper making became common here, although the first mill was established in 1690, and the industry developed without interruption.

4. Early Methods of Converting Rags into Paper.—The early phases of the development of paper making are interesting. The first process for converting the rags into paper was crude and primitive. The rags were washed, and were then steeped in closed vessels for several days. During this treatment, a fermentation process took place which brought the mass to a pasty consistency. This pulp was then diluted, transferred to the vat, and made into sheets on a hand mold. (See *Hand-made Papers*, Vol. V.) The first advance from this method came with the introduction of stamping rods, to beat the rags into pulp; and this was the process in use in practically all of the small mills previous to 1750. The rags were washed, and were then transferred to oak tubs or mortars, partly filled with water. Here the rags were beaten and pulped by stamping rods, which were encased with an iron shoe at one end. In most of the mills, these stamping rods were operated by power from a small stream—in a few cases they were operated by hand. By this method, using water power, from 100 to 125 pounds of rags would be reduced to pulp in 24 hours in a typical mill.

5. During the period from 1750 to 1800, the Hollander beater engine was developed and brought into general use. This was a small and early type of the beating engine so well known today. Its introduction brought the first decided change in manufacturing equipment. It improved quality, increased production, and made possible the later rapid growth of the industry.

6. Paper-Making Raw Materials.—Prior to 1860, rag fibers, cotton and linen (as well as some straw, jute, and hemp), formed the total source of paper-making raw materials. Rags were used in all grades of paper, from news and wrapping paper to writing paper. This condition made rags very scarce, in spite of large importations from Europe. In 1850, more than twenty million pounds of rags were imported by the United States, and still the mills were short of raw material. The newspapers and periodicals of those days were full of pleas from paper-mill proprietors, asking the people to save their rags for some particular paper mill. The difficulty in obtaining a sufficient supply of raw material was the determining factor in the industry. Expansion was almost impossible.

The discovery of the processes of making pulp from wood—the soda, sulphite, and groundwood processes—finally relieved this situation, and gave the industry the opportunity to grow. Esparto was introduced as a substitute for rags in 1856.

7. At the present time, most of the rags go into the class of paper known as *fine writing*, and for this type of paper the fiber from cotton or linen cloth has no equal; large quantities of low-grade rags are used for roofing papers, while burlap, strings (jute) and hemp rope are used for strong wrapping papers (manilas). These fibers are prepared for use directly in the paper mill, as distinguished from wood fibers, which receive their first treatment in the pulp mill. For this reason, and because of the considerable similarity in processes and apparatus, the preparation of straw and esparto grass is also included in this Section.

NOTE.—**Cotton**[1] (gossypium). The cotton fiber, which is the basis of most rag papers, consists of a single hair-like cell, which is flattened and twisted when fully ripe. This appearance is a characteristic of fully matured cotton; it is not shown by unripe fiber or by that which has been injured

[1] Data on the characteristics of paper-making fibers, given in these notes, are based on information derived from Chemistry of Pulp and Paper Making, by E. Sutermeister. See also Section 1, Vol. III.

during growth. The fibers form the covering of the cotton seed, and they are removed from the seed by ginning. The length of the cotton fiber varies from 2 to 5.6 cm., and the diameter varies from 0.0163 to 0.0215 mm. The cell walls of mature cotton are thin, and they often present a granulated appearance or highly characteristic cross markings. Müller has analyzed raw cotton, with the following results:

	Per Cent
Water	7.00
Cellulose	91.35
Fat	0.40
Aqueous extract (containing nitrogenous substances)	0.50
Ash	0.12
Cuticular substance (by difference)	0.63
Total	100.00

SOURCES OF SUPPLY

8. New Rags, or Table Cuttings.—The supply of new rags for paper making comes largely from textile or garment factories, where cuttings and scrap ends of cloth are collected as by-products. The total amount of cuttings available from this source of supply is estimated at 40,000 tons per year. The only other use for this material seems to be the re-spinning of white knitted goods, and this in quantity only when the price of raw cotton is high.

This waste material is usually sold to a broker or middleman, who takes the entire accumulation of the individual factory; and it may include everything, from the floor sweepings to the choicest clippings of white linen or cotton. The middleman usually repacks this material and then sells it to the paper mills that use the different grades.

9. Old Rags.—The source of supply of old rags is quite different. In the first place, it is much more flexible. Being a waste product, so common to every home, there is little likelihood of a shortage; for a rise in price will always bring out rags. We are all familiar with the grotesque figure that travels our streets and alleys buying "ra—gs" from the housewife. His capital consists of a dejected horse and a dilapidated wagon. Each night he sells his day's collection to another rag man who owns a small warehouse, and who buys these mixed rags and bales them in carload lots, for sale to the grader. The **grader** sorts

the rags for re-sale (sometimes directly and sometimes through a broker) to the paper mill, in the case of cottons, or to the shoddy mill, in the case of woolens. The following figures give a slight idea of what a thousand pounds of mixed rags contain.

PAPER-MAKING RAGS

	Lb.
No. 1 whites	25
No. 2 whites	50
Whites and blues	225
Jute bagging	125
Roofing stock	250
	675

NON-PAPER-MAKING RAGS

	Lb.
Soft woolens	20
Hard woolens	125
Mixed linseys (half wool and half cotton)	20
Wiping rags	60
Quilts and white batting	85
Rubbish	15
	325
Total	1000 lb.

10. Uses of Rags.—No. 1 whites, No. 2 whites, and whites and blues, (known also as either twos and blues or thirds and blues) are used for writing paper, and the specifications for each of these grades will be found in Arts. **13** and **14**. The jute bagging is used by the wrapping-paper mill, and the roofing rags are used for making roofing paper. This is the lowest grade of stock; it includes everything, so long as it is rag.

The woolen rags go to the shoddy mills; they bring by far the highest prices of any of the grades.

Wiping rags are used by machine shops, etc., and consist of large pieces of good, sound, colored cloth.

Quilts and batting go to the mattress industry. The rubbish consists of such material as old straw hats, shoes, etc., which must be baled and carted to the dump.

11. Transporting and Handling Rags.—Rags are transported and handled in machine-pressed bales that weigh from 400 to 1000 pounds, depending on the size and type of press. The

hand baling press is still largely used; it is by far the most economical method of baling where only a small number of bales are made each day. With this type of press, two men will turn out from 10 to 15 bales a day.

Where the volume of baling to be done is large enough, the power press is of course more economical. There are several types of those presses on the market, any one of which does excellent work. A bale weighing 600 to 800 pounds is large enough for convenient handling in the mill.

CLASSIFICATION OF RAGS

SPECIFICATIONS

12. General Specifications.—There are certain general rules which should apply to all grades. Rubber, for example, in any form is a distinct menace to the manufacture of good paper; and it should be generally understood that rubber is not to be included in any of the packings of rags that are to be used for the manufacture of writing paper.

All grades, new and old, must be free of rubber, leather, wool, silk, paper or muss, unless otherwise specified. It is recommended that where a description of any grade is not available, the material is to be sold on specified sample.

Other general specifications, which should cover all grades of rags, unless they are sold strictly on representative samples, are: they should be dry, and they should be free from paint, grease, and other foreign materials.

SPECIFICATIONS BY GRADES

13. Old Rags.—Old rags are divided into various grades, each of which has its own trade name and specifications, which are as follows for old rags:

Extra No. 1 white cottons consist of large, clean, white cottons, free from knits, ganzies, canvas, lace curtains, collars, cuffs, shirt bosoms, bed spreads, new cuttings and stringy or mussy rags.

No. 1 white cottons consist of clean white cottons, free from lace curtains, ganzies and canvas. Need not be so large as

Extra No. 1 white cottons. Must not contain stringy or mussy rags.

No. 2 whites consist of soiled white cottons, free from dump rags, street rags, scorched rags, paint, greasy rags, or oily rags. Also free from button strips and seams from higher grades of whites.

Mixed whites should contain at least 40% of No. 1 whites and not more than 60% of No. 2 whites. They must not contain any of the material prohibited in the grades of which they are composed.

Street whites should consist of soiled white cottons from street or dump collection. They are likely to contain some foreign material, resulting from the manner in which they are collected, but the rags must be dry.

Twos and blues should be rags of strictly house collection, and should consist of No. 2 white cottons and light blue checks and prints. They should not contain the seams or buttons taken from higher grades of whites, nor should they contain dark blues of any description. They should not contain old corsets, small pieces of new rags, or rags smeared with paint, oil, or grease, nor should they contain any scorched rags.

Thirds and blues should be rags of strictly house collection, and may contain light pinks, greens, and blues, but should be free from dark reds, yellows and blacks, from quilts and feather ticks, canvas, tents and awnings, seams and strippings from higher grade rags, from rags smeared with paint, oil, or grease, and from small pieces of new rags or fine cut mussy rags.

Miscellaneous blues should be rags of all colors, free from solid black or satinet. Street or dump rags must not be present in excess of 25%.

Old blue overalls are to contain clean, blue overalls only, free from oil, grease or paint, and are understood to be free from miners' garments.

Black cotton stockings are to consist entirely of black cotton stockings, but white feet or edgings are permitted.

White cotton batting should contain only clean white cotton from quilts, mattresses and comforters; must be stripped of all rags.

White cotton-filled quilts should be quilts filled with white cotton batting only.

No. 1 white old lace curtains are to contain only clean, white lace curtains, free from starchy, knitted or crocheted material.

Besides these grades there are special classifications, such as underwear, flannelettes, hosiery, tarpaulins, filter press canvas, strings, rope, burlap, roofing stock, etc.

14. New Rags.—For new rags, the names of the grades and their specifications are:

No. 1 white shirt cuttings, heavy, are to consist of white cuttings such as accumulate from shirt factories and similar sources; must be strictly table cuttings and are to be free of starchy or loaded material. B.V.D. cuttings (dimity) may be included.

No. 1 white shirt cuttings, lawns, may contain materials of lighter weight than heavy shirt cuttings; they must be table cuttings and free of starchy or loaded material.

No. 2 white shirt cuttings are to consist of white shirt cuttings and lawns, consisting of house to house and shop collections, and not of table cuttings; may contain a small percentage of black threads, muss and soiled material; are to be free from oily rags.

No. 1 bleached strips, white or gray, are to consist of strips of white or gray cotton cuttings, coming from bleacheries; must be clean.

No. 1 soft unbleached cotton are to consist only of unbleached cuttings of a character similar to white shirt cuttings, heavy. Must be free of starchy or loaded rags, Canton flannels, shivy rags and drills.

No. 1 bleached shoe cuttings should be table cuttings of a nature used in lining shoes; are to be free of pasted stock.

No. 2 bleached shoe cuttings are the same as No. 1, but may contain pasted stock.

No. 1 unbleached shoe cuttings are to be the same as No. 1 bleached shoe cuttings, with the exception that they are to consist of unbleached cuttings and are to be free of pasted stock.

No. 2 unbleached shoe cuttings are the same as No. 1, but may contain pasted stock.

No. 1 fancy shirt cuttings are to be such table cuttings as accumulate from shirt factories and similar sources, consisting of white background with colored stripes.

No. 2 fancy shirt cuttings are to be composed of the same material as No. 1 fancy shirt cuttings, with the exception that

they need not be table cuttings; but must consist of material coming from house to house and shop collections; may contain black threads and soiled pieces.

Blue overall cuttings are to be such table cuttings as accumulate from overall factories and similar sources. This grade should be accompanied by sample showing whether the weave consists of a black-thread or white-thread back.

Washables or wrapper cuttings must be table cuttings; may contain material of lighter weight than fancy shirts, such as calicoes, ginghams, etc.; may contain solid colors, but are to be free of reds and blacks.

New light seconds are to consist of sheer, flimsy rags, light colored; solid colors are to be admitted or white backs with colored stripes. Need not be free from black threads.

Soiled bleachery rags are to consist of cuttings and remnants coming from bleacheries; may be soiled, but must be free from oil and grease.

No. 1 dark prints are to consist of all dark colors and unbleachable new material.

Cottonades are to consist of coarse, striped cotton-garment cuttings that look like wool but are free from wool. Brown cuttings and striped overalls may be included.

Besides the classes given, there are other grades and subdivisions. An interesting article on Rags, by Howard Atterbury, appeared in the *Pulp and Paper Magazine*, 1919, p. 1103.

TREATMENT OF RAGS BEFORE COOKING

PRELIMINARY THRASHING

15. The Rag Thrasher.—The first step in the actual preparation of rags for paper making is the preliminary thrashing.

The bales are opened up and the rags put through a rag thrasher, though some mills pass new rags directly to the sorters. The purpose of this machine is to open the rags up thoroughly, and to remove the loose dirt and dust that may be present.

The rag thrasher consists of a revolving cylindrical drum *A*, Fig. 1, about 40 inches in diameter, from which protrude hooks or pins *B* for thrashing the rags. The cylinder is enclosed, and there is a hopper *C* and gate *D* on one side for feeding in the rags,

and a gate *E* on the other side, for discharge after the rags are thrashed. Under the cylinder is a coarse screen *F*, which allows the dirt to drop through, but which holds the rags in contact with the drum. At the top, a stick of timber *G*, about 12 inches from the drum, serves as a whip as the rags beat against it. Fine dust held in suspension is removed by a suction fan through the pipe *H*. The dirt is shoveled out from below the screen.

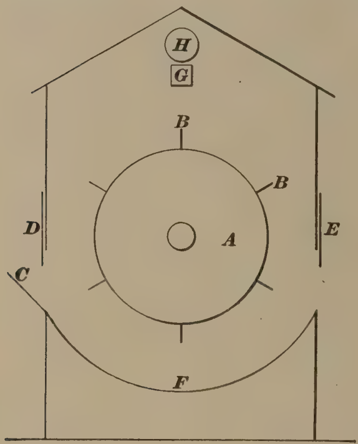


Fig. 1.

In operation the hopper is filled, then the gate is opened, and the rags are allowed to slide into the thrasher. After 4 or 5 minutes' thrashing the rags are discharged by raising the gate on the other side. They are then ready for the sorters.

16. Thrasher Dust and Loss in Weight.—Loss in weight due to the amount of dust and dirt taken out by the thrashers depends largely, of course, on the character of the rags going in. In the case of new table cuttings, the loss is very small; while in the case of street whites, it may run as high as 8 % to 10 % or higher.

SORTING AND INSPECTING

17. Sorting Rags.—From the thrasher, the rags usually are loaded into baskets and turned over to women, who *strip* and *sort* them. These sorters work at tables, Fig. 2, which are really shallow boxes with a coarse screen bottom. Large scythe-like knives are used for stripping buttons, ripping seams, cutting large rags, etc. In the case of new rags, there is usually very little stripping to do. The sorters in this case look particularly for foreign material, such as metal, rubber, leather, etc., that must be taken out, and also for the occasional pieces of silk or wool or paper that may be there. Pockets are always searched; the findings include knives, rings, money and trash.

In the case of old rags, the sorter's work is more difficult. These old rags consist mainly of cast-off cotton garments.

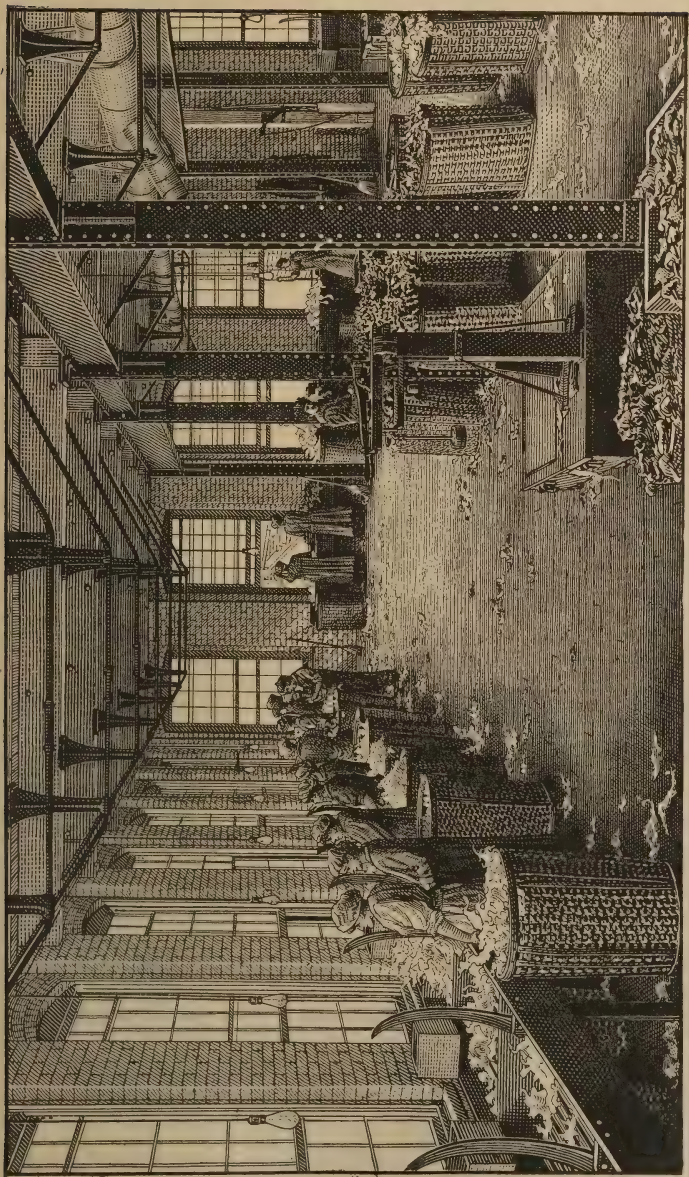


Fig. 2.

These garments must first be stripped on the knife; that is, the buttons are stripped off, the pockets and heavy seams ripped up, and all metal is taken off. When this is finished, the rags are graded as to color, where this is necessary, separate baskets receiving the different grades and colors; for instance, yellows and reds, known as "hard" colors, as they are hard to bleach, are saved for dark-colored paper. The strippings and discarded stock make what the paper maker knows as **muss**, and this material goes into the manufacture of roofing paper. Good woolens go to the shoddy industry.

18. Why Rubber and Metal Are Avoided.—Perhaps the reader is wondering why the paper maker speaks so often of rubber and metal, and is so anxious to avoid them. It is due to the desire on his part to make clean paper. Hold a sheet of writing paper up to the light and look for the dirt. Now rubber and metal are not affected by the cooking, the washing, or the bleaching. Once in, they go straight through the process, only getting cut up into small pieces and finally spreading through the whole web of paper. "But," one may ask, "How is it that you sometimes find such things as rubber in new cuttings of cotton cloth?" It is there because of the large amount of rubber used in making cotton garments. There are rubber waist bands, sleeve bands, dress shields or goods waterproofed or pasted together with rubber. Such things as these, carelessly allowed to go in with good material, cause losses of thousands of dollars annually to the paper industry. Constant alertness is the only safeguard against troubles of this sort.

19. Inspection of Rags.—Rags coming from the sorters are usually sent to the inspectors or "over-lookers." These women go over the rags again very carefully, to make certain that all of the objectionable material is removed from the rags before it is passed on to the next process. The rag sorters must do conscientious work, if the mill is to make clean paper. Workers in the rag room are usually paid a certain amount per pound for rags sorted. This weighing is also a check on the quality of rags and quantity used.

20. Equipment of Rag-Sorting Room.—The equipment of the rag-sorting room is not elaborate. The rags are handled in large baskets, which are provided with casters, for ease of moving from place to place. The sorters work on tables provided with

half-inch-mesh wire screens on the working surface, this allows dirt, loose buttons, etc., to drop through into a box. Each of the sorters has, in addition, the stripping knife, set up in a convenient place on the table or screen at which she works; this is a source of accidents, usually of a minor nature, but likely to cause infection; even a scratch should be given first-aid treatment.

Particular attention must always be given to the ventilation of the rag room, and a special ventilating system should be provided to remove the dust and lint that always comes from handling the rags. A fan usually draws the dusty air in a gentle stream from just below the screen and delivers it to a large chamber, where the air practically comes to rest, and the dirt settles out.

CUTTING AND DUSTING

21. Reason for Cutting.—As the rags come from the sorters and inspectors, they are in fairly large pieces. In order to prevent them from roping, to produce uniform *half-stuff* (washed rags), and to facilitate handling all along the line, the rags are cut into pieces averaging in area from 10 to 20 square inches. For many years this work was done by women; now, however, the rag-cutting machine is practically always used, except in the case of linen rags, where the hand-cutting of rags is still quite general.

22. Rag Cutters.—The essentials of this cutter, Fig. 3, are a revolving knife cutting against a bed knife (like a lawn mower), and the means of feeding the rags to this knife. In many of the mills, two cutters in tandem are used. Tandem cutters are set at right angles so as to cut the rags in both directions.

23. One of the most recent machines on the market is the rag cutter, shown in Fig. 3. This machine uses slitters before the knife, and its operation is as follows: The rags are placed in the feed apron *U* at the top, and from there they fall in between the corrugated knives, or *slitters* *X*, which constantly rotate and slit the rags into strips lengthwise. The rags are stripped off these slitters by another set of corrugated rolls, and *clearers*, and fall into the intermediate, or slat, apron. This carries the strips along and feeds them endwise to the fly knife *A*, which

turns against a stationary bed knife and chops off the strips into rectangular blocks. The cut rags then fall to the delivery apron *W*, which carries them to the duster. All gears should be enclosed and care taken to keep hands from the knives. The bed knife is lowered or lifted by means of hand wheels *H* and screws, so as to regulate the distance from edge of bed knife to fly knife *A*.

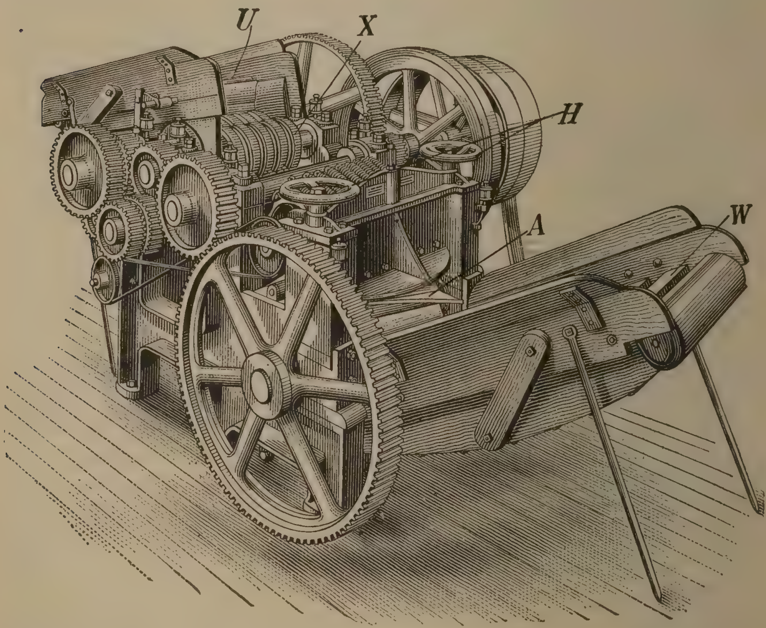


Fig. 3.

24. Dusters.—Rags, coming from the rag cutter, carry with them the dust produced by the cutting operation. This dust is too short-fibered to be of use, and would be lost in the later processes; it also carries with it a very considerable amount of dirt, which has to be taken out, if clean paper is to be made. For this purpose, different types of dusters are in use. Very often the rags are discharged from the rag cutter to a **railroad duster.** In this type of duster, revolving drums *A*, Fig. 4, with pins or teeth arranged helically around the drum, carry the rags over fine screens *C*. This type of duster is very simple. The rags are fed in at *D*; after passing the screen, they are deflected to

the next drum by the shape of the hood at *E*. This duster is rather harsh in its treatment of the rags, and the fiber loss is considerable. On the other hand, the harsh treatment eliminates a large amount of dirt, so that its use is common on old rags. The dirt collects in the box below the screen. The rags usually fall from the outlet *F* upon an apron conveyor.

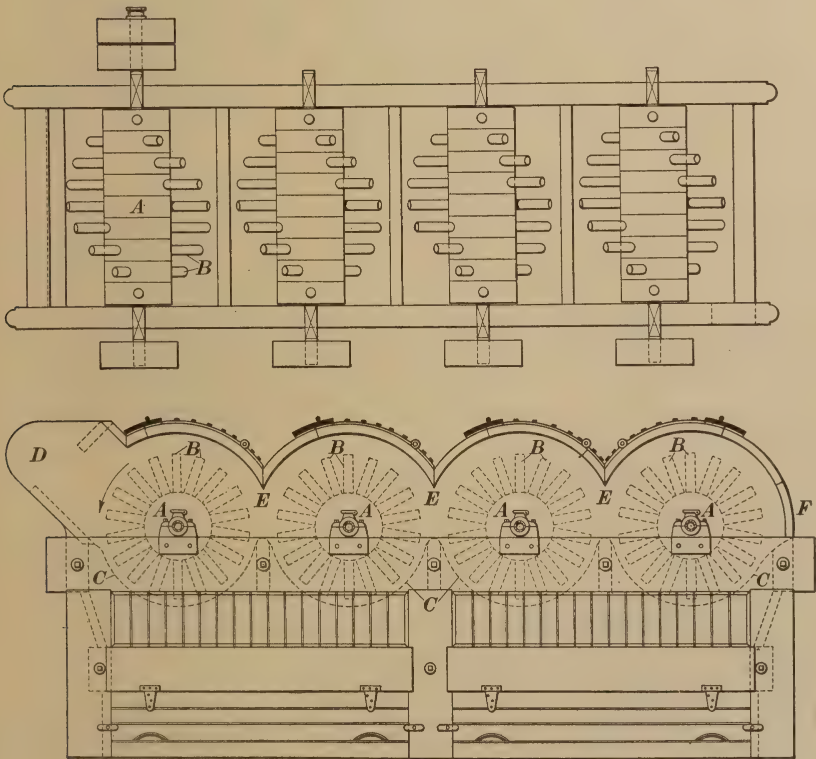


FIG. 4.

Another type often used is the **fan, or wing, duster,** Fig. 5. Here the rags are blown through the duster by a revolving drum *A*, with wings *B* arranged helically. At the same time, the outside screen *C* revolves in the opposite direction. *D* is the dust outlet. This makes an excellent duster, and is a type very generally used. Here the treatment is not so severe, and the fiber loss is less.

The cut rags are handled from the rag cutter to the boiler on aprons or in chutes; hence, cutting and dusting, and loading of the boiler really take place as one operation. Often, however, it is necessary to prepare and pile the rags in advance.

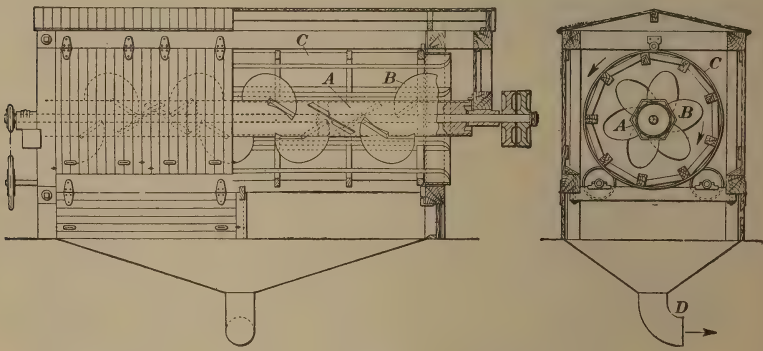


Fig. 5.

25. The Magnetic Roll.—In spite of all the care used in sorting and inspecting the rags, if metal is present, a certain amount of it always gets by. The magnetic separating roll, Fig. 6, has been applied, within the last few years, for removing as much as

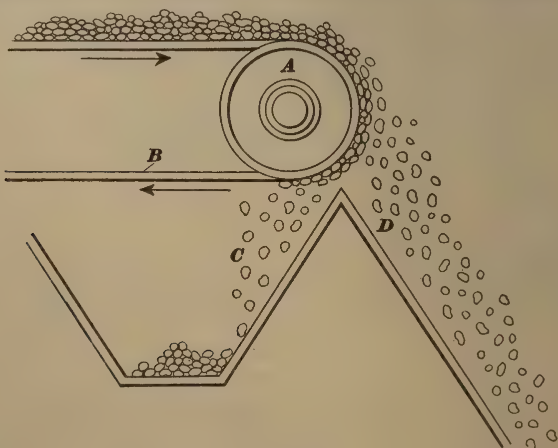


Fig. 6.

is possible of this material. The magnetic pulley *A* is placed as the driving roll on one of the aprons *B* carrying the cut rags. Rags *C* containing iron or steel cling to the pulley, and are thus separated from the other rags *D*.

The following extract from a letter written by a manufacturer, in whose mill a magnetic separating pulley has been installed, gives some idea of what this pulley can accomplish:

"Tests show that we are taking out approximately 500 pieces of metal from each 10,000 lb. of old rags, run through. This material consists of hooks and eyes, metal clasps, tacks and nails, metal buttons, pins, needles, pieces of wire, etc., which are not detected by the women inspecting the rags. We estimate from several tests that this is about 75% of the material which it would be possible to take out in this way.

Our separator roll is 12 inches in diameter, and is run at 76.8 r.p.m. This gives us an apron speed of 241 feet per minute."

QUESTIONS

(1) Name some of the materials first used for keeping records.

(2) As regards source of supply and character, how do new rags differ from old rags?

(3) (*a*) Of what do the sortings from paper-making rags consist? (*b*) what uses are made of them?

(4) How much loss is suffered in thrashing?

(5) (*a*) Mention some sources of rubber and iron in rags; (*b*) what effect have they on paper?

(6) Explain one type of duster and what it does.

COOKING OF RAGS

COOKING AND COOKING LIQUOR

26. Purpose of Cooking.—It may now be asked why the paper maker cooks the rag before making them into paper? In other words, what does this cooking process accomplish? We know that wood is cooked to get rid of the impurities (particularly lignin), and a pure cellulose is left. Now linen and cotton fibers are the nearest thing to be had in nature that corresponds to pure cellulose; but the rags used in paper making contain many undesirable impurities, which should be removed. First of all, the cooking softens and mellows the rag by removing the natural waxes and resinous material in the fiber. In addition, it removes the dirt and grease and loosens up the starch and loading material. It also starts the color in rags that have been dyed, and thus renders them readily bleachable. In some mills, it is the practice to take certain new white cuttings directly to the washing

engine, leaving out the cooking process. The writer does not consider this to be the best practice, although it is feasible in the case of new white cuttings. These rags are harsh, and they do not respond nearly as well to treatment as in the case where the same rags are mellowed by the cooking process. Uncooked rags are usually rather difficult to size properly; because, where the natural waxes have not been cooked out, the capillary attraction of the central canals is very hard to overcome with rosin size. Several high-grade mills have thoroughly tried out this practice, and they now insist that all rags shall be cooked.

NOTE.—Most of the fibrous raw materials that are treated in the paper mill are relatively pure cellulose, which is practically unaffected by the relatively mild alkaline cooking liquors and the weak oxidizing action of bleach solutions, in properly conducted mill operations. Cotton, linen, hemp and jute have already passed through operations, incidental to the textile and cordage industries, which have largely removed the non-cellulose matter originally associated with the fiber. With esparto, straw, bagasse, etc., the treatment is necessarily more severe than with textile wastes; but here too, the recovered cellulose has come through unaffected, because of its wonderful resistance to most chemical agents. Some of the more important reactions of cellulose have been mentioned in the Section on *Chemistry*, Vol. II, and the Section on the *Properties of Wood*, Part 2, Vol. III.

27. Cooking Liquor.—There are three different cooking liquors in general use in cooking rags: the liquor made with caustic lime; that made with caustic soda; and that made by using a combination of caustic lime and soda ash. Much has been written and said as to the advantages of any one of these processes over each of the other two, widely divergent opinions have been expressed, and two investigators reach diametrically opposite conclusions. Such being the case, no attempt will here be made to settle this argument. It is reasonably certain, moreover, that with careful handling, rag pulp (half-stuff) that is of excellent quality can be produced with any one of these cooking liquors. A few of the points usually brought up in a discussion of this subject may be of interest, however.

28. Lime or calcium hydrate attacks the natural waxes energetically, and at a temperature of 120°C. (248°F.) they are saponified in less than two hours. Lime also attacks, but less readily, the oils or grease that may be present in the rags. The one big drawback is that it forms calcium salts, most of which are not soluble, and, being rather sticky, they adhere to the fiber.

This makes the washing much more difficult, since the small particles of lime soap must be carried away mechanically in the wash water. It is to be noted, however, that this is not an insurmountable obstacle, and that rags cooked with lime are being washed satisfactorily all over the country every day. In addition, it is to be remembered that lime is especially adapted to the decomposition of a large number of dyestuffs used in coloring cloth; being a weak alkali, it has no action on cellulose. Consequently, it is used very widely because of the excellent color obtainable with it. Paper makers have long claimed that when lime is used in the cooking, the resulting product does not have nearly as much tendency to turn yellow as is the case when caustic soda or soda ash is used.

29. Caustic soda is of course a more active agent than lime. It readily attacks the natural waxes and the oils or grease that may be present in the rags. It removes glues and starch sizings thoroughly, and it forms products that are soluble in water and which are easily washed out. In strong solutions and at high temperature, the cellulose itself may be acted on. The writer's experience has been, however, that it does not attack the colors as thoroughly as does lime.

30. The liquor made with a combination of lime and soda ash is, of course, a mixture of the other two, with a certain amount of calcium carbonate in suspension. The soda present increases its causticizing action, and it more effectually removes the albuminous substances that may be present. As with the lime alone, however, the resulting products are all insoluble, since any sodium salt formed will immediately be precipitated by the lime, to form the calcium salt and caustic soda. Rags of dark color and very dirty rags are best cooked in the caustic soda or lime-soda ash liquor. When lime CaO and soda ash Na_2CO_3 are mixed in solution, the lime first forms the hydrate $Ca(OH)_2$, then the following reaction occurs:

$$Ca(OH)_2 + Na_2CO_3 = CaCO_3 + 2NaOH$$

The $CaCO_3$, calcium carbonate, settles out, leaving a solution of caustic soda $NaOH$.

31. The tank in which the liquor is prepared is usually so situated that the liquor can be transferred to the boiler by gravity, through pipes; it usually holds the quantity required for one cook or one "bleach." If lime is used, the tank should contain an

agitator, similar to that in a vertical stuff chest (See Section on *Beating and Refining*); and the resulting liquor should be screened before going to the boiler or to storage, in order to make sure that all lumps are removed. When lime and soda ash are used, the latter should first be dissolved, then the necessary lime should be added and well stirred. Let settle, and draw off through a strainer.

BOILERS

32. Types of Boilers.—The cut and dusted rags are usually fed into the boiler by a chute, which feeds into the manhole at the top. In the rotary boiler, which is the one in general use, the rags must be packed into the boiler by a man inside. This

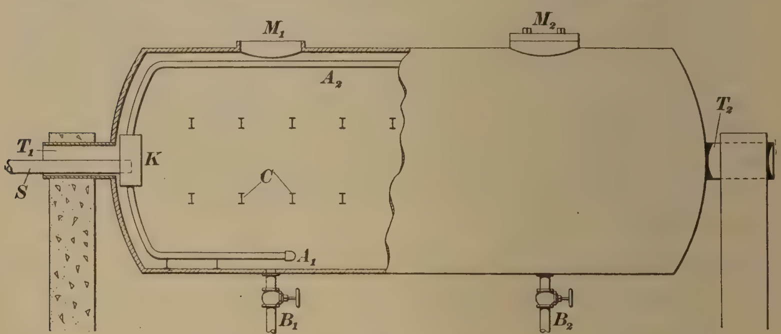


FIG. 7.

man tramps down the rags and stows them into the sections of the boiler not reached by the chute. He should wear a respirator to keep dust from his lungs. When the boiler is partly filled, the cooking liquor is started in, for when the rags are wet they pack much more closely. It is essential that the boiler be packed evenly and well to obtain uniform cooking. The liquor pipe is introduced through the manhole at which the man is not working. An open vertical pipe, stuck into the boiler, assists in finding the liquor level.

33. The boiler in general use in this country is the cylindrical rotary shown in part section in Fig. 7. This is a large cylindrical drum (usually about 8 feet in diameter by 24 feet in length) of such dimensions that it will hold about 5 tons of rags. In practice, the cooking liquor, made up with water if necessary, is brought up to the level of the journals T_1 and T_2 and, in some

cases, even filling the boiler two-thirds full; more water forms as the cooking steam condenses. During the cooking process, this boiler turns at the rate of about one revolution per minute. Note that the steam is admitted directly through pipe S in the trunnion T_1, and is distributed by the different lengths of pipe, A_1, A_2, usually three, opening at $\frac{1}{4}$, $\frac{1}{2}$, and $\frac{3}{4}$ the length of the boiler. In order to avoid the possibility of burning the rags, nearly all of these boilers are equipped with the Kinne valve. This is a sleeve-type valve, situated in the journal at K, and so set that steam can enter the distributing pipe only when the pipe is in a

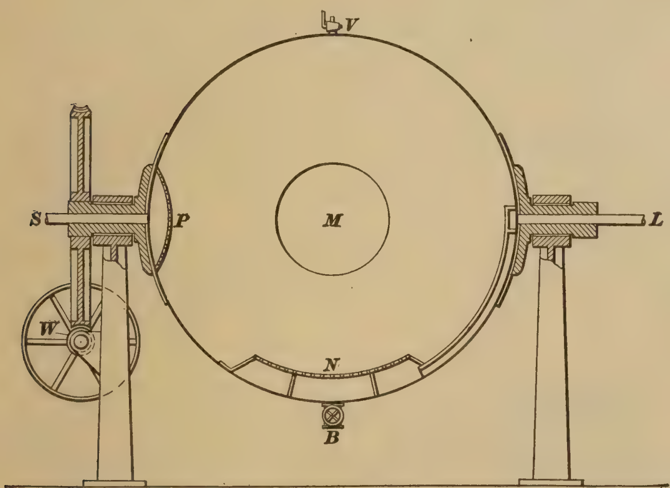


Fig. 8.

position below the cooking liquor, as at A_1. However, in many rag boilers, steam is introduced directly at the trunnion through a perforated plate. B_1 and B_2 are blow-off pipes, the inlets of which are covered by screens; C indicates V-shaped spikes, to keep rags from being rolled into ropes; M_1 and M_2 are manholes. At the end of the cook, the liquor is drained or blown off through B_1 and B_2; it is not profitable to recover the chemicals in it.

When the cooking operation is finished, the steam is turned off and the boiler is stopped, with the valves B_1 and B_2 at the bottom in position to connect with the blow-off pipes; this connection is made, and the valve is opened. The steam pressure blows off the cooking liquor, which carries with it large amounts of insoluble material in suspension. When the cook is thoroughly

blown, the pipes are disconnected, the manholes are opened, and the boiler is rotated as long as rags fall out readily; then it is brought to a position such that the rags may be pulled out by the workmen (using long-handled hooks) into cars or onto the floor, to drain.

34. A boiler of the same general type, largely used in England and Europe, and somewhat on this continent, is the revolving spherical boiler shown in Fig. 8. This boiler is set on trunnions, and is operated on the same principle as the cylindrical rotary; it finds some factor in cooking straw. Its main advantage is that higher steam pressures can be carried in it; it also empties a little faster than the cylindrical form of boiler, but has less capacity.

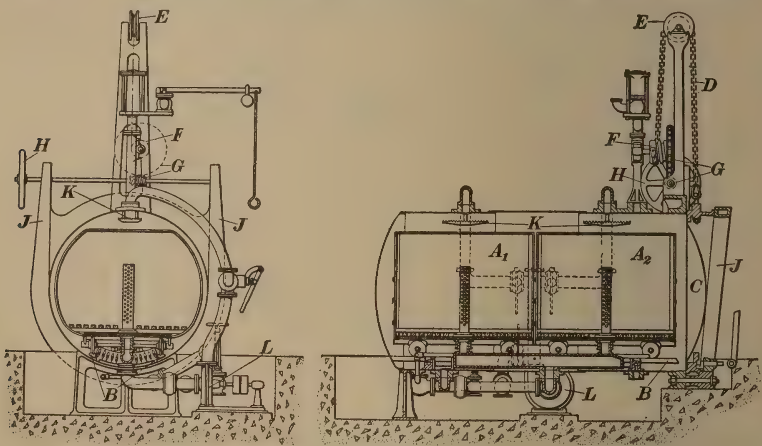


Fig. 9.

The boiler is turned by means of the worm gear and pulley mechanism *W*. Steam enters at *S*, and is distributed by the perforated plate *P*; lye enters at *L*, or through the manhole; *V* is an air vent; *B* is a blow-off valve; *N* is a perforated plate; and *M* is a manhole, for charging and emptying.

35. Another cooker that may be of interest is the **Mather kier,** Fig. 9, which is an adoption into paper making from the textile industry. It has been applied to the cooking of rags for paper making in England, and the results reported seem to merit attention. The following data are given in a report by Cross and Bevan. "Its dimensions are 8 feet long by 7 feet in diameter, and it is adapted to hold two wagons A_1, A_2, of special design, which are run into the kier on tracks *B*. In order, however, to economize

time, six wagons are employed, four being either filled or washed, while the other two contain rags in process of treatment in the kier. The cut and dusted rags are delivered automatically from a chute, directly into the wagons. The running of the wagons into the kier and the closing of the door *C* occupy only some 2 or 3 minutes. The door is lifted by means of chain *D* passing over pulley *E* to chain drum *F*; the latter is attached to worm and worm wheel *G*, which is operated by hand wheel *H*. The door slides between frames *J*, which are wedge shaped; thus the farther the door slides down, the tighter the joint between it and the body of cooker. As soon as door *C* is closed, the rags are saturated with caustic-soda solution, which is delivered through sprays *K*, from a tank above the kier, and is circulated by means of a centrifugal pump *L*. Steam is turned on until the pressure reaches 10 pounds, and the process is continued for from 2 to 3 hours, according to the nature of the material. The steam is blown off, which occupies about 15 minutes, the door is opened, the wagons are removed, and another pair run in, the three latter operations occupying only 10 minutes. The rags, after being withdrawn from the kier are washed by flowing water on the top of the wagons. This kier is capable of doing at least 40 tons of rags per week, and it is adaptable to all classes of rags."

36. Among the advantages claimed for the kier are: (*a*) A notable improvement in the color of the rags, both before and after bleaching; (*b*) economy in washing time; (*c*) saving in steam; (*d*) improved strength of fiber; and (*e*) an enormous saving in space—one kier doing the work of several boilers.

37. The possibilities of washing the rag with hot water before its removal from the boiler are worth careful thought. This procedure results in a brighter-colored stock and a considerable saving in washing time in the washing engine, besides making use of the heat in the boiler and rags.

38. Cooking with Lime.—Caustic lime alone is widely used on this continent for cooking new, white cuttings. In the mills making the highest grades of writing paper, where such grades of rags as hosiery clips, white shirt cuttings, etc., are being used, the almost universal practice is to employ lime alone for the cooking. These rags are always clean, and they do not need the severe causticizing action of caustic soda, which has a tendency to make rag stock yellow. The excellent color produced by

cooking with lime is another factor determining its use for that particular purpose. Lime, also, is the cheapest alkali. The usual practice in cooking this grade of rag would be as follows:

For 5 tons of rags 600 pounds of lime would be used. The pressure carried in the boiler would be 30 to 40 pounds, and the cooking time 10 to 12 hours.

In using lime there is the question of just what kind of lime it should be. Careful thought points to the conclusion that there is but one kind of lime, the use of which is admissible,—that is a straight calcium lime. In the manufacturing of sulphite pulp, a lime containing a high percentage of magnesium is sought after and used with good results. For a rag mill no such advantage holds and the presence of any considerable amount of magnesium makes that part of the lime almost useless for cooking rags. Magnesium hydroxide is relatively even more insoluble than calcium hydroxide and its action is almost negligible.

NOTE.—The time required varies with different lots of rags, according to color, dirtiness, etc., and must be determined by experience. Cooking too long wastes time, steam and sometimes fiber. Too short a cook means more trouble in washing, excessive bleach consumption, and probably a harsh stock for the beater.

39. Cooking with Lime and Soda Ash.—The next general class of rags to be considered includes new cuttings of unbleached or colored material such as blue overall cuttings, unbleached shoe cuttings, shirt cuttings, etc. For cooking this type of rag, a combination of lime and soda ash is generally used. When cooking these rags, it is advisable to keep the chemicals fairly high, to take care of the fragments of cotton seed hull, so often found. The paper maker calls them "shives," and they must be thoroughly cooked to prevent their appearance in the finished sheet of paper. The usual treatment of this type of rag is about as follows:

For 5 tons of rags, use 1000 or 1200 pounds of lime and 300 to 400 pounds of soda ash. The pressure would be carried at 30 to 40 pounds, and the cooking time would be about 15 hours.

40. Cooking Old Whites.—Old rags are divided roughly into two types or classes; one of which is the type known as *old whites*. This class would include the No. 1 whites, the No. 2 whites, and the street-soiled whites. There is some variation in the general practice with regard to these rags. Many of the

mills use lime alone on the better grades, while others use a combination of lime and soda ash. An average procedure might be this:

For 5 tons of rags, use 600 pounds of lime and 50 pounds of soda ash; cook at 25 pounds pressure for 12 hours.

This rag has usually been washed many times before it comes to the paper mill, and, as a result, the natural waxes and resins of the fiber have already been pretty well removed. The purpose of the cooking, then, is to remove the oils, grease and dirt that may be present. This being the case, it would seem that the addition of a small amount of soda ash to the cooking liquor would perhaps be the better practice.

41. Cooking White and Colored Cotton Mixtures.—The other class of old rags is that in which there is a mixture of white and colored cottons, as twos and blues, thirds and blues, etc.

In cooking this type of rag, both lime and soda ash are used. The lime helps materially in producing a good white, and the soda ash is needed to bring up the causticity of the cooking liquor to a point where it will more efficiently attack the dirt and grease present. The usual treatment for this type would be as follows:

For 5 tons of rags, use 1200 pounds of lime and about 150 pounds of soda ash. Cook at 25 to 30 pounds pressure for 12 to 15 hours.

42. Cooking Linens.—In the cooking of linen rags, as in the case of cotton, no general rule can be laid down, as very much depends on the particular character of rags to be cooked. The cooking liquor is either caustic soda or a combination of soda ash and lime. For a new, white linen, free from shives, the cooking treatment is rather mild; 2% of caustic soda, with a pressure of about 20 pounds for 6 hours, would cook the rags thoroughly.

For old linens or new gray linens, which are quite likely to contain shives, a fairly strong liquor of lime and soda ash is needed. Here the pressure would be advanced to 30 to 35 pounds, and the time to 10 or 12 hours.

NOTE.—**Linen** is composed of the bast fibers of the flax plant, *Linum usitatissimum*. The plant yields about 8% of fiber, which is separated by retting and is then known as *flax*. The ultimate fibers are 6 to 60 mm. long, and are 0.012 to 0.026 mm. wide, the average ratio of length to

width being about 1200:1. The fibers are thin-walled tubes, with thickened places or knots at intervals; the ends are tapered, the walls rather transparent, and the canal is small. Two samples of Belgian flax have been found to contain 81.99% and 70.55% cellulose.

43. Use of Caustic Soda.—In England and on the continent of Europe, caustic soda is largely used in cooking all grades of rags, lime being recommended only for the very cheapest. The amount of caustic soda used varies from 1% to 4% or 5% of the weight of the rags, depending, of course, on the nature of the rags to be cooked. It is well adapted for rags containing albuminous and starch sizings, and it readily attacks oil, grease and dirt. The rags are easily washed, and they make excellent rag pulp. It is generally recognized, however, that cooking with lime will give a pulp of better color. If the question of cost is to be considered, lime is cheaper by far than the caustic soda.

44. Variations in Cooking Practice.—To date, there is no definite evidence as to the comparative strengths of rags cooked with lime as against those cooked with caustic soda. The fact that both processes are in excellent repute leads to the belief that no great difference will be found one way or the other. There is considerable variation in practice among the different mills with regard to the cooking pressure and the duration of the cook. In some mills, the practice is to cook at a high pressure and for a short length of time, while in others, this practice is reversed. It is very seldom necessary to exceed a pressure of 40 pounds or a cooking time of 18 hours.

Whatever the practice of the particular mill, it is generally agreed that rags should be thoroughly cooked. Well-cooked rags wash easily, bleach easily, and produce a whiter pulp. They respond better to treatment, and produce better and more nearly uniform paper. It is a mistake to undercook rags, with the idea that they will produce a stronger or more durable paper.

WASHING RAGS

45. The Washing Engine.—Fig. 10 is a plan and longitudinal section typical of the Hollander type of washing engine, which is most common. It consists of an open tub *A*, in which the rags and water circulate. The circulation is maintained by the roll *R*, which throws the rags over the back-fall *B*. In front of the roll,

shown in section, is the button catcher C; this is a recess in the floor, covered by a metal grid, and its purpose is to catch any buttons, metal, sand, etc. that may still be in the stock. In many cases, a second button catcher is installed just behind the back-fall. The roll, or fly, bars J are set about 3 inches apart in notches in the circumferences of three disks, keyed to shaft S, and the spaces are filled with wedges of wood. The bed plate P is made up of metal bars interspaced with wood. For a washing engine,

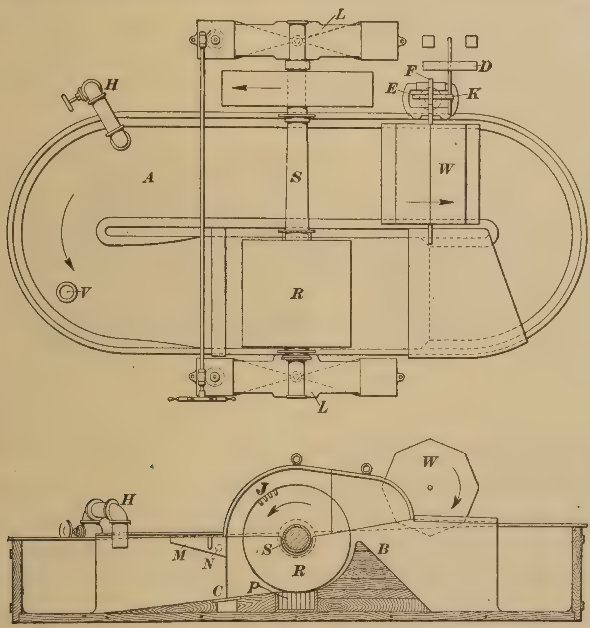


FIG. 10.

bed plate should be of the type that the paper maker calls a *slow plate*, say $\frac{1}{4}$- or $\frac{3}{16}$-in. bars, spaced with $\frac{1}{4}$- or $\frac{3}{16}$-in. wood. The roll, making 90 to 100 r.p.m., or even 120 r.p.m., draws the rags over this bed plate and draws them out; *i.e.*, unravels the weave. At some point like V (shown in the plan) is a valve for dumping the washer. L, L, are the **lighter-bars** (levers), on which the roll bearings rest, and by means of which the roll is raised or lowered through the action of a worm gear and screw, described in detail in the Section on *Beating and Refining*. A hydrant, situated at H, is the means of furnishing water to the washer. For washing oily rags, where much foam is produced, the foam may be skimmed off by a strainer of coarse-mesh wire M, which

allows the foamy water on top to pass out the outlet N, retaining the rags. W is the washing cylinder described in Art. **46.**

46. Fig. 11 shows the principle and construction of a washing cylinder. Two octagonal wooden heads A_1 and A_2 are carried by the shaft B; A_1 is fastened to the shaft by a spider, which gives an outlet through the sleeve C. Both heads are slotted radially, as at D, from the center to each vertex (corner), and also from each vertex perpendicular to these slots, as at E. Boards F are slipped into slots D, meeting at the center, and ending flush with slots E. Boards G fit slots E, and are planed at the edge flush with the sides of the octagons, leaving a space

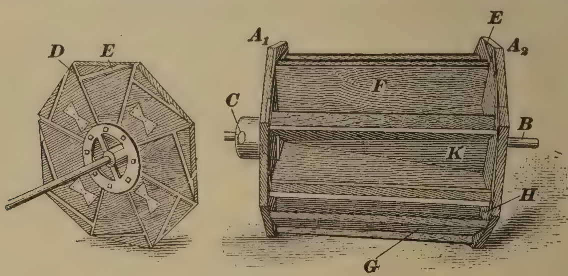


FIG. 11.

H for water to enter as the drum turns. A fillet K deflects the water to the outlet C as each pocket rises. Wooden gratings, covered with copper or bronze wire screen of 50–60 mesh, are screwed to the heads and complete the cylinder; the screen prevents much loss of fiber, though some short ones get through. The cylinder W (Fig. 10, which also see) turns at the rate of about 12 r.p.m., being lowered by a ratchet so that a gear E on shaft F engages a pinion K made fast to a pulley D, which is driven by a belt from the roll spindle S. A washing engine may carry from one to four of these drums, as may be necessary.

Another type of washing apparatus is shown in the Section on the *Treatment of Waste Papers*.

47. After the rags leave the boiler, they are usually allowed to stand in the cars for 24 hours. Evidence has shown that by standing in this way, the dirt is more readily washed out, and a better color is obtained on the half-stuff. Before the rags are furnished to the washer, some sort of foam killer should be added, especially in the case of rags cooked with soda ash or caustic soda. A pint of kerosene oil to each 300

pounds of rags is as effective as most of the prepared or patented foam killers.

48. The Washing Process.—The washing engine is partly filled with water, the roll taken up well off the bed plate, and the rags furnished, meanwhile adding water gradually. Soon after the furnishing is completed, the washing cylinder is let down, and the hydrant valve is so regulated as to give all the water the cylinder can take out. For the first hour, the engine should have plenty of water, and the roll should be kept well off the plate, so that it is just brushing the rags. Putting the roll down too soon will rub the dirt into the fibers, and the result will be poor color. After an hour's washing, the color will usually be such that the washerman can begin to bring down his roll and take the fiber out of the rags. This must be a slow process, and the roll should be lowered gradually and often instead of *vice versa*. As the washing progresses, the amount of wash water may be reduced, especially if it is necessary to supply a maximum to another washer that has just been furnished. The rags are washed until the effluent is practically clear, and until the fibers are well drawn out of the rags. Care must be taken not to cut the fibers, for long half-stuff is much better than short half-stuff; the beaters can shorten the fibers, but can't make them longer.

49. Discussion of Washing.—An important consideration in the paper-making process is the water. Cellulose readily absorbs organic coloring material from it, and becomes yellowish; iron is sure to cause discoloration in white or delicately tinted papers. One hundred gallons a minute is a very reasonable amount to use in a thousand-pound washing engine. This means a lot of water; and if organic coloring materials are present in quantity, there is a marked effect on the color of the half-stuff. Clean, colorless water is a necessity where fine papers are made.

The time given for washing the various grades or classes of rags runs from $5\frac{1}{2}$ or 6 hours to perhaps 14 hours, in a few extreme cases. In the case of linens, white shirt cuts, hoisery, etc., the length of treatment is determined by the time needed properly to draw out the fiber; 8 to 12 hours covers the range in this class. For such rags as overall cuttings and the like, 8 hours is a fair length of time. In the case of old rags, the time needed to wash them clean is an important factor. For thirds and blues, 6 hours is the usual time.

In all the above cases one hour is allowed for bleaching after the washing itself is finished, and bleaching is the next subject to be considered here.

QUESTIONS

(1) Name the three kinds of liquor used for cooking rags, and give the molecular formulas of the chemicals in each.

(2) Mention an advantage and disadvantage of each kind of cooking liquor.

(3) How is cooking liquor prepared?

(4) What kinds of rags are best cooked with (*a*) lime? (*b*) lime and soda ash? (*c*) caustic soda?

(5) Why should rags be thoroughly cooked?

(6) (*a*) What are the principal features of the washing engine? (*b*) State the function of each.

BLEACHING, DRAINING, AND LOSSES

BLEACHING

50. Theory of Bleaching.—In the process of bleaching, the impurities that cover up the natural whiteness of the cotton fiber are oxidized and removed; the fiber itself will stand the action of reasonable bleaching without being impaired.

While there are many possible bleaching agents, chlorine or a chlorine salt is the most economical, and is the one generally used. The bleaching, or oxidizing, is not due primarily to the action of the chlorine, but rather to the fact that the chlorine reacts with water, liberating oxygen. This oxygen attacks and destroys nearly all coloring materials and impurities, changing them to colorless or soluble substances, and restores to the cellulose its natural color. A slight yellow color can be compensated for by proper dye-stuffs. Taking, for example, the case of bleaching powder, which is most used, this reacts somewhat as follows (see Sections on *Elements of Chemistry*, Vol. II, and *Bleaching of Pulp*, Vol. III): In solution in water,

$$2CaCl(OCl) \rightarrow Ca(OCl)_2 + CaCl_2;$$

then,

$$Ca(OCl)_2 + 2H_2O \rightarrow Ca(OH)_2 + 2HClO,$$
$$2HClO \rightarrow 2HCl + 2O(\text{nascent}),$$
$$Ca(OH)_2 + 2HCl \rightarrow CaCl_2 + 2H_2O.$$

The final products of the bleaching powder are, then, calcium chloride and oxygen in the nascent state. The oxygen unites with the impurities to form less objectionable compounds. The action of liquid chlorine is very much the same; the final products being oxygen and hydrochloric acid. The intermediate reaction is:

$$H_2O + Cl_2 = HCl + HClO.$$

Soda ash is usually added to neutralize the hydrochloric acid so formed, giving NaCl and H_2O and CO_2. It is to be noted that acids are injurious to the fiber, and that they affect some coloring matters.

51. To get the largest yields in the preparation of bleach liquor from bleaching powder, special care must be given to the process. Yields of 85% to 95% of the actual available chlorine present are possible, but yields of 60% to 80% are, unfortunately, rather common. One of the first things to determine is the strength to which the liquor shall be made up. A few minutes thought will prove that the lower the Baumé test of the liquor the more water may be used in washing the sludge and the higher will be the yield. On the other hand, the Baumé test must not be run too low, because of the greatly increased storage facilities needed. A liquor testing 4° Baumé is perhaps the most economical. The sludge remaining in the settling tank should always be washed once, perhaps twice; the latter is usually possible only when the liquor that results from the second washing can be used with new bleaching powder, to prepare the strong liquor.

52. Preparation of Bleach Liquor.—The method of preparation of bleach liquor is briefly as follows:

The powder and either wash water or fresh water are put into a tank having a mechanical agitator, like an ice-cream freezer, or like the vertical stuff chest shown in the section on *Beating and Refining*. The whole is mixed, and the lumps are thoroughly broken down. This mixture is then pumped to the settling tank, where as much water as is needed is added. The minimum settling time for reasonable yields is 24 hours, and wherever possible, 48 hours should be allowed. This liquor may then be run off from the sludge into the storage tank, using either wash liquor or water, as the case may be, to bring it to the required degree Baumé, *i.e.*, the desired chlorine content. See Vol. III, §9, Art. **56**.

Extreme care must always be taken to see that the liquor in the storage tank is clear, which means that a high calcium lime should be used for making the bleaching powder. A bleach liquor that is turbid, due to carelessness in running from the settling tank, will lose much of its action in the washer.

53. The Bleaching Process.—Before adding the bleach liquor to the washing engine, the roll should be taken up off the plate, the wash water turned off, the excess water removed, and the washing cylinder raised. The bleaching liquor may then be slowly added. The usual practice in American mills is to add an acid substance as an accelerator, after the bleaching liquor is in; this must be done with great care. A few pounds of alum to each washer makes a very good accelerator, and is safer than acids, such as acetic acid, but especially HCl and H_2SO_4. It assists in converting the $Ca(OCl)_2$ to $HClO$. The use of an *antichlor* is common in neutralizing occasional excess of bleach; but it cannot be unqualifiedly recommended, because, in most cases, the cure is as bad as the disease. Sodium hyposulphite, sodium sulphite, and calcium sulphite have all been used, usually in the beater, and many others have been suggested and tried. The use of antichlor, however, is becoming more and more the exception in the bleaching of rags. The bleaching may also be hastened by warming the stock, as by blowing in steam before adding the bleach; the temperature should not exceed 100°F.

After the rags have been brought to color, the excess chlorine should be washed out by lowering the washing cylinder and turning in fresh water; a very slight excess may be left in the drainer. Excess of bleach (free chlorine) is detected by using the starch-iodide indicator; see Vol. III, §9, Art. **60**.

There is a further method of washing the excess chlorine from the rags, which gives excellent results. When the bleaching is nearly complete, the rags are dropped into the drainer. After the drainer is filled, 12 hours is allowed for the rags to come up to color. At that time, two or three washers of water are put down on the drainer of half stock.[1] This process is repeated 12 hours later. In this way, practically all traces of chlorine are removed.

54. Use of Liquid Chlorine.—During the last few years, the use of liquid chlorine for bleaching rags has been demonstrated as a commercial possibility; and it now seems likely that within

[1] **Half stock** or **half-stuff** is defibered raw material that is ready for the beater. See Art. **27**.

the next five years its use will become quite general, since it is both convenient and more economical than bleaching powder.

The only apparatus required in order to use it is that for transferring it and measuring it into the washing engine. A scale

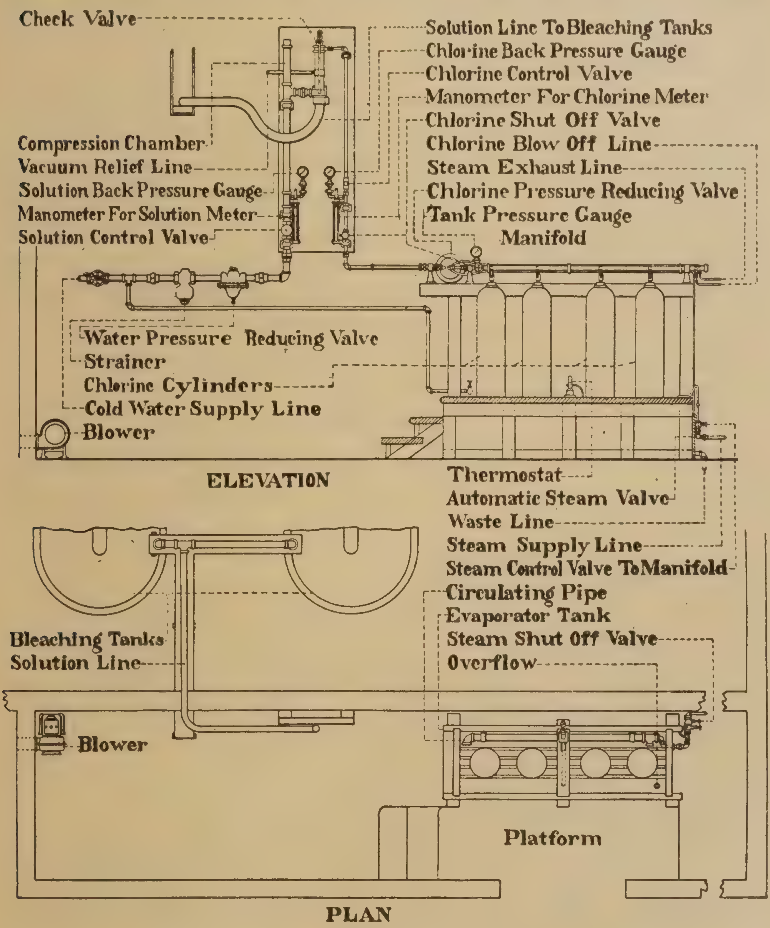


FIG. 12.

for weighing the container, and an injector, accomplishes this readily. Fig. 12 shows a diagram of a typical installation.

55. In using liquid chlorine it has been found that the white produced on the half-stuff has a slightly reddish tinge, which replaces the slightly yellowish tinge that is produced with bleaching powder. This, however, can be easily corrected in coloring.

Soda ash is generally added, to neutralize the HCl formed in the bleaching reaction; otherwise, the acid would attack the fiber, the steel of the beater roll, and the paper machine. Experience has shown that a pound of chlorine gas will do the work of about 10 pounds of bleaching powder, which may be figured roughly as one-third chlorine; it is always ready for use, and no mixing and settling tanks are required.

56. Amount of Bleach Needed.—The amount of bleaching powder required in bleaching rags naturally varies considerably, both with the color of the rag before bleaching and the color to which it is desired to bring the rag half stock. For new white cuttings, the amount of bleach used is about 1%, or 10 pounds of bleaching powder in solution for a thousand-pound washer. At the other extreme, for such rags as Thirds and Blues, from 5% to 6% of bleaching powder is generally used.

DRAINING

57. The Drainer.—When the half-stuff in the washing engine has come up to color and the chlorine is washed out, the valve

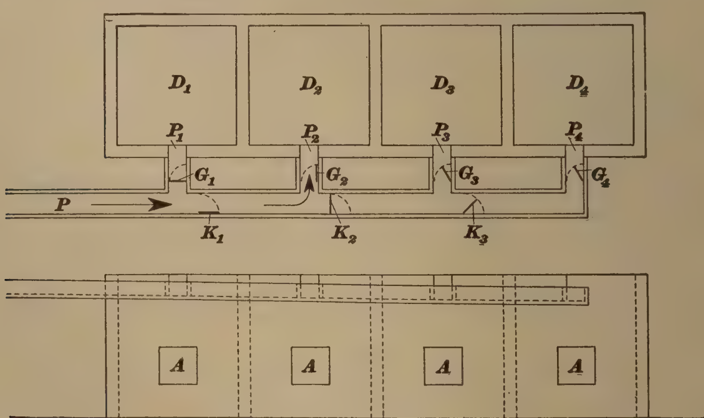


Fig. 13.

in the bottom of the engine is lifted and the last of the material is raked down to the valve, whence it flows into the drainer through a system of pipes and valves, Fig. 13. D_1, D_2, etc. are drainers. The stock comes down in pipe P. To fill any drainer, as D_2, all preceding side pipes, P_1, etc., are closed by valves G_1,

etc.; G_2 is opened and the main pipe closed as at K_2, preventing stock for drainer D_2 from filling the remainder of P and later passing to another drainer. The pipe line is often a plain wood box. Sometimes the gates G_1, G_2, etc. are hung so as to swing across either the main channel P or the side channels, P_1, P_2, etc., thus eliminating gates K_1, K_2, etc.

The purpose of the drainers is well expressed in the name; *i.e.*, they allow the water to drain from the stock and to take soluble impurities with it. In addition to this, the drainer also provides for rag half-stuff, storage sufficient to take care of the necessary variation between the consumption and production.

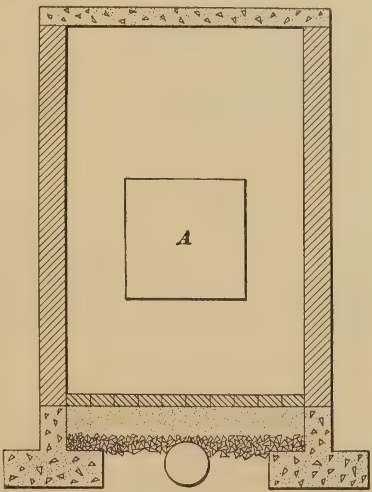


FIG. 14.

The drainer is a small room, which may be 20 feet long by 8 to 10 feet wide, and about as high. It is of masonry construction throughout, except for a wooden door *A* (Fig. 14). This door is an opening in the front of the drainer; it is about 3 feet square, and about 3 feet from the floor. Fig. 14 shows how the floor of the drainer is constructed. When the special tile (perforated with holes wider at the bottom) is used, the false floor is laid on concrete, with a slight slope to a main drain.

58. Time that Stock Is in Drainer.—Rag stock should usually be left in the drainers for two to three weeks for best results. It is possible to use the stock in a shorter time, and, in the exceptional case, stock may stay in the drainer for several months. In the latter case, however, it is usually advisable to freshen the stock by letting a washer of water and bleaching liquor down on top of it. This helps materially in the subsequent use of the stock.

The possibilities of washing the stock in the drainer by putting down washers of water on it, have been discussed fully above, and the subject need not be given further consideration here. Care must be taken that as each kind of stock comes through from the boiler, a drainer is empty and clean, ready for it.

59. Possible Use of Wet Machine.—It has often seemed that it might be possible to adapt a wet machine (used for de-watering wood pulp, as described in the Section on *Treatment of Pulp*) to this problem of draining rag half-stuff. If this could be accomplished, many advantages would be gained. The half-stuff could be taken from the machine in laps of uniform moisture content, and the question of weight of rag half-stuff (a rather dubious figure in most mills) could be settled. The rags might

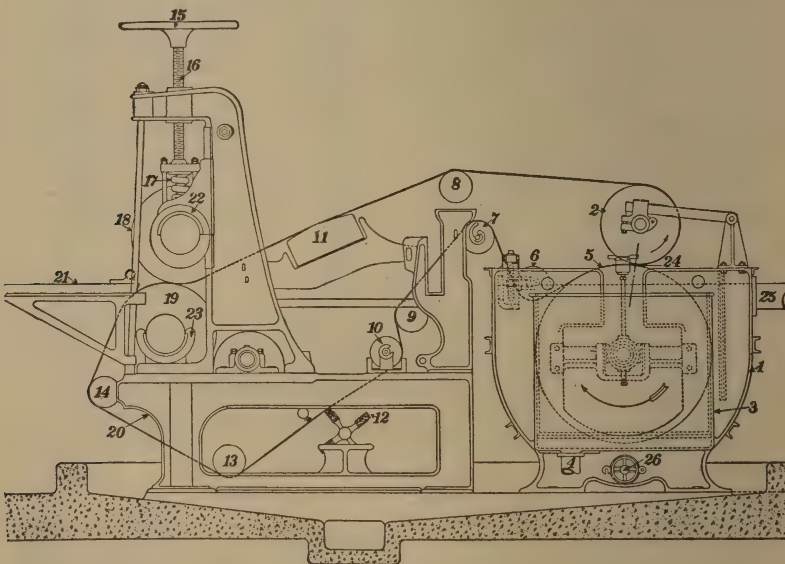


Fig. 15.

be piled directly on skids, and these, wrapped if necessary, could be put in storage, in the same manner as pulp. The writer feels that this method would keep out much of the foreign dirt that is occasioned by handling the stock from the drainers to the beaters in stock cars. In addition to this, a much more rigid inspection of the product would be possible, since many of the troubles would show up at once on the wet machine and not at the end of the paper machine.

Fig. 15 illustrates a wet machine. The thin stock enters the vat 1, through pipe 25; 26 is a washout. The cylinder 5 collects fibers from the stock as water passes through the screen surface of the cylinder and out at 3 and 4. An endless woollen

felt, pressed down by the couch roll 2, takes the layer of fiber from the cylinder, carries it over the suction box 11 and between the press rolls 18 and 19; it winds up on 18, is cut off when the layer is right thickness, and is folded into a bundle or lap on table 21. Pressure on roll 18 is adjusted by two mechanisms 15, 16, 17. The felt is carried on rolls 6, 7, 8, 9, 10, 13, and 14, and is washed by a shower and whipper 12. A lap from a 72-inch machine will weigh about 50 lb., and will contain about 30% to 35% of fiber.

The practical questions are of course whether the long rag half-stuff could be handled by a wet machine satisfactorily, and whether the full bleaching effect of the chlorine would be obtained in the shorter time of contact.

LOSSES IN THE PROCESS

60. Total Losses.—In each step in the preparation of rag fibers, there is an attendant loss in weight. Roughly the weight of half-stuff will run from 65% to 80% of the weight of raw material purchased, depending of course on the grade of rags in question and the care used in the processes of treatment. There is also a considerable loss in weight in storing rags. Rags in storage for several months will lose up to 4% in weight. This is almost entirely a moisture loss, and it is probably fully regained in the processing.

61. Losses in Detail.—The first actual loss comes in the removing of the tare (wrapping). Under trade customs, this is limited to 3%, and, usually, it will not average quite as high as this. Any tare in excess of 3% is chargeable to the dealer from whom the rags were purchased.

62. There is some loss in the rag thrasher. In the case of new cuttings, this would probably be very slight—not over $\frac{1}{2}$%. On street or dump rags, however, losses here amounting to as high as 10% or more are not unusual. In the case of cleanly packed Thirds and Blues, the loss here will usually be close to 2%. The dust from the thrashers consists of dirt, buttons, etc., with considerable fiber dust, which is thrashed out. Such dust is salable to roofing mills and to mills making some of the lower grades of coarse papers; it is usually called a **No. 2 dust.**

63. The next loss to be considered is the sorting loss. This, too, depends very largely on the grade of rags being sorted. New cuttings may run as low as 1% or 2%; while in the case of old rags, this loss will run from 5% up, depending on the quality of the rags. In the case of thirds and blues, from 5% to 6% is about the loss to be expected where the best rag obtainable is used. The out-throws are largely what is known as *muss*. This consists of strippings, seams, etc., in short, such material as must be thrown out of the rags being sorted; it contains metal and rubber in abundance. Material that is sorted out because of its color goes into what is known as blacks, and this consists of hard or fast colors (as red and yellow) and blacks. As in the case of the dust, this material is readily salable to lower grade mills, and is used in the manufacture of certain of the cheaper grades of coarse papers and roofing papers.

64. There is a further loss at the rag cutter, which is practically constant, regardless of the grade of rags being cut; it is due to the dust formed by the cutter knives, which is separated from the rags by the dusters at that point. The loss in dust at this point will run from 1% to 1½%, depending somewhat on the equipment used. This form of dust is called **No. 1 dust**; it is much superior to No. 2 dust, being fairly clean and consisting largely of short fibers.

65. In determining the losses due to cooking, washing, and bleaching, these three processes are usually linked together, because of the difficulty of arriving at the weight and consequent losses at any intermediate step. Moreover, these yields are always rather difficult to determine accurately, even though one considers the three processes together; for the rag that is once wet in the bleach boiler is not dried out again until it gets into paper. At their best, then, these figures are not any too accurate.

66. In the case of new cuttings, a yield of 85%, based on the weight of the dressed rags, is a figure that is fairly accurate. This figure would of course be too high in cases where the rags were heavily loaded with starch or other material.

In the case of such rags as thirds and blues, a yield of 75% to 80%, based on the dressed weight of the rags, is about what should be expected. For street whites, however, this yield would be considerably lower, and would be nearer 60% than 75%.

Many things may come into individual lots or types of rags that would change these yields entirely. For the general run of rags, however, they should prove out fairly accurate.

QUESTIONS

(1) (*a*) What bleaching agent is generally used for rags? (*b*) how does it act?

(2) How can an excess of bleach be gotten rid of?

(3) As regards purpose and manipulation, compare the drainer with the wet machine.

FIBERS OTHER THAN RAGS

HEMP, JUTE, SEED-HULL FIBER, ETC.

HEMP

67. Use and Importance.—By far the most important of the **hemp** fibers used for paper making is the *manila hemp*. This fiber is used very largely by a group of mills known as makers of rope papers.

The largest tonnage of these papers goes into sacks, the first in importance being flour sacks, but also including sacks for sundry uses, such as cement, lime, plaster, etc. The manila-rope fiber is used on account of its great fiber strength; also, for the pliability of the product which it produces.

Manila-rope papers used for cable insulation purposes probably rank next in importance. The copper conductors in power cables are insulated by a number of wraps of rope paper, slit in widths from $\frac{7}{8}$ inch to 2 inches, after which, the whole cable is saturated with insulating oil compounds. In telephone cables, the fine conductors are insulated with a single thickness of very thin manila paper, which is left dry in the final cable. Other uses of manila paper are for sand paper, shipping tags, gaskets, pattern paper, and the like.

NOTE.—**Hemp** (*Cannabis sativa*). The fiber is prepared by retting, from filaments that run the entire length of the stem. The ultimate fibers composing these filaments vary from 5 to 55 mm. in length, averaging 22 mm. in length and 0.022 in diameter. The ratio of length to diameter is, there-

fore, about 1000:1. The fibers have very thick walls, which are not very highly lignified. The ends are large and sometimes flattened, and the central canal is almost obliterated. In microscopic appearance, the fibers are very similar to those of flax; but they differ from linen in having greater ability to break down into fibrillæ (fibrils) during the mechanical process of paper making. Müller gives the cellulose content of a sample of raw Italian hemp as 77.13%. Many other plants yield fibers to which the name hemp is given; but they are generally distinguished as manila hemp, sisal hemp, sunn hemp, etc.

Manila hemp (*Musa textilis*). Manila hemp is prepared from the outer sheath of the stems of the musa, which is a species of banana. The ultimate fibers are from 3 to 12 mm. long, averaging about 6 mm. The width varies from 0.016 to 0.032 mm., averaging 0.024 mm., the ratio of length to width being about 250:1. The fibers taper very gradually toward the ends; the central canal is large and very prominent, while fine cross markings are numerous. The percentage of cellulose in raw manila is given by Müller as 64.07%.

Agave. Among the most common of the fibers of this class is sisal hemp, or heniquen, which is largely employed for cordage, bags, etc., in which forms it reaches the paper mill. The ultimate fibers are longer than manila fibers, rather smaller in diameter, tapering and pointed at the ends, and comparatively stiff. The central canal is not prominent, but can be seen as a narrow line in some of the fibers. The walls are thick; they are characterized by many fine cross lines, close together, which are found on nearly every specimen.

68. Source of Supply.—The manila fiber used in these papers is practically confined to old manila rope. The old rope is collected by junk dealers, usually sold by them to larger dealers, who, in turn, sell it to the rope-paper mills. Such old rope is usually collected at definite places; such as sea ports, important lake or inland shipping points, gas- and oil-well districts, etc. A very considerable amount of old rope for paper making purposes is imported into this country from European points. The manila fiber for rope making comes from the Philippines, and it represents one of the principal products of these Islands.

69. Preliminary Treatment.—The rope is inspected, first, on being unloaded and, again, and more intimately, at the rope cutters, where any foreign material or fibers other than manila are thrown out. The rope is cut by what is known in the trade as *rag cutters*, but the knife equipment of these is so modified as to produce longer pieces. The length of the manila threads after passing through the rope cutter ought to be about 2 inches. The cut rope then goes through rotary dusters, which open up the fibers and eliminate much of the loose dirt.

70. Cooking.—From the dusters, the cut rope is then fed into the rotary boiler. This is the same type of boiler as is in general use for cooking rags, and it holds approximately 5 tons. The cooking liquor is made from lime and soda ash; and, as is the case with rags, the strength of the liquor, the time of the cooking, and the steam pressure vary with the results to be obtained and the characteristics of the particular lot of rope at hand to be cooked. Average conditions would be about as follows:

For a 5-ton boiler, use 1000 pounds of lime and 500 pounds of soda ash; cook at 25 pounds pressure for 10 hours.

This cooking process removes the natural waxes and loosens up the foreign dirt and grease. It makes the fiber softer and more pliable, and greatly improves its working qualities.

71. Washing and Bleaching.—The washing and bleaching are usually done in the beater, that is, as different parts of the beating process, without recourse to the half-stuff, or ordinary, method of treatment. The rope-paper mills generally use beaters of from 800 to 1300 pounds capacity. Ordinarily, the cooked fiber is furnished directly to the beater; and the washing cylinder is lowered and the washing process is carried out in much the same manner as rags are washed in the washing engine. When the washing is completed, the bleach is added. After bleaching, the washing cylinder is again lowered, and the excess of bleach is washed out. From this point, the ordinary beating process is continued. The amount of bleach is quite low, as a pure white is not attainable and is never attempted. Moreover, a great many of the papers are entirely unbleached; but if bleached, the usual quantity of bleaching powder consumed is from 5% to 10% of the weight of rope furnished.

72. Yield.—The yield of manila rope as bought, compared with the amount of paper made, will run about 50% to 65%, depending on the thoroughness of the cleaning, cooking, and bleaching treatments. It can be readily seen that a satisfactory paper for cement sacks can be produced with much less cleaning than is required for a light-weight, telephone insulating paper.

Mention should be made here of the use of *true hemps*, which are employed in Europe for certain special papers, such as Bible, cigarette, etc. The true hemp is prepared by methods described; but in the beater, it acts like linen, the fiber splitting

longitudinally into fibrils which can be felted into a sheet possessing exceptional formation, strength, opacity, and finish. This fiber bleaches to a much better color than manila hemp.

JUTE

73. Use and Importance.—The **jute** fiber is the isolated bast of the jute plant, which is an annual of very rapid growth, attaining a height of 8 to 10 feet in the hot Indian climate. To obtain the bast fiber, the plants are cut down and steeped or *retted* in a pool of stagnant water. By this means, a fermentation process is started. When the retting is completed, the bast layer (which is between the bark and the wood) is stripped off and washed, and goes in this form to the textile mill, where the fiber is spun and woven into twine or burlap.

Jute fiber is extensively used in the manufacture of wrapping paper; it produces paper of excellent strength and durability, being second only to hemp. Attention must be called at this point to the fact that jute is not a pure cellulose fiber, being what is termed a ligno-cellulose, and it is used as such in paper making. On this account it bleaches to a bright yellow color, and this, of course, places certain limitations upon its use. The fiber is also used to some extent in buff drawing paper and other papers of that type.

74. Source of Supply.—As is the case with cotton, the raw fiber is much too high in price to permit of its direct use by the paper maker. Moreover jute cloth goes almost exclusively into sacks and other articles, which are cut without waste, so that new cuttings of jute are not on the market. This limits the supply of the paper maker to old sacking, burlap, and string, and practically all of the jute used is from this source. As is the case with rags, it is collected and sorted and turned over to the paper maker in bales.

The fiber from the butt of the jute plant is not suited to spinning; and a few years ago, these jute butts were used to a considerable extent by paper makers. This stock is very dirty and not particularly desirable, and its use is considerably restricted.

NOTE.—**Jute** (*Corchorus capsularis* and *C. olitorius*). The fibers of jute are about 2 mm. long and 0.022 mm. in diameter. They are thick-walled; the central canal is very variable, at times being of considerable width and then

narrowing to hardly more than a line. The surface is quite smooth, and there may be noted at intervals radial canals and joints, which are similar to those in linen, though not so pronounced. Jute contains about 63% cellulose and 24% lignin. As exported, the composition of the bast varies, the fiber content ranging from 49% to 59%.

75. Preliminary Treatment.—The preparation of jute for paper making varies considerably with the particular type of paper that is to be made from it. Obviously, in the case of a high-grade drawing paper, much more care must be taken in the sorting, washing, and bleaching than would be the case when a much cheaper product, such as wrapping paper, is to be made. In the former case, the jute bagging is put through the thrasher; it is then sorted over rapidly by women, who take out the foreign material that may be present and any pieces of rotted bagging. The stock is then ready for the cutter, where it is cut, dusted, and delivered to the boiler for cooking. The ordinary type of rag cutter and duster is used, and the boiler is the cylindrical rotary, in nearly all cases.

76. Cooking.—The reasons for cooking jute are similar in many respects to the reasons for cooking rags. The cooking removes the foreign dirt and loading and the natural waxes of the fiber, leaving it in such condition that it responds readily to subsequent treatment. In cooking jute, no attempt is made to cook out the lignin—the object is simply to prepare a ligno-cellulose fiber for use as such in the paper-making process. This being the case, it is the practice to use fairly low temperatures or pressures, say, 20 pounds. The cooking time most commonly used is about 10 hours, although this may be varied 2 hours either way in the different mills.

It is the almost universal practice to use lime as the cooking chemical. While the quantity varies somewhat with the condition of the stock and the result desired, the usual practice is to use from 10% to 20% of lime.

77. Washing and Bleaching.—In general, jute is washed and bleached by the same processes as rags. In most cases, however, the stage known as half-stuff is omitted, the washing and bleaching being done as a part of the beating process. That is, instead of dropping the stock into the drainer after it is washed and bleached, the beating operation is continued in the same engine, without interrupting the process. In this case, the stock is furnished into

the engine after it has been cooked and is then throughly washed with the washing cylinder. When the washing is complete, the bleaching liquor is run in, and the stock is allowed to bleach up to the desired color. Dry bleach is often added directly to the engine when bleaching jute. It is usual to "sour" with a little H_2SO_4 to hasten the bleaching action; but free chlorine may form yellow lignin chloride. The excess bleach is then washed out with the cylinder washer; and from this point, the beating operation proper begins.

In bleaching jute, about 8% of bleaching powder, figured on the dry weight of the fiber, is used, and the stock comes up a bright yellow color. Liquid chlorine cannot be used successfully, as the bleaching solution must be alkaline.

78. Yield.—The yields from the jute fiber vary considerably, depending on the care with which the preparation of the fiber is conducted and the degree of washing and bleaching. Since the half-stuff or intermediate form is usually omitted, it is convenient to consider the yield of paper from the baled weight of the jute; in the average mill, this yield varies from 50% to 65%.

SEED-HULL FIBER, BAGASSE, ETC.

79. Cotton-Seed Hulls.—When the cotton seed comes from the cotton gin, there is left on it a fuzz of short cotton fibers, firmly attached to the seed. This will amount to approximately 200 pounds of fiber per ton of seed. It has long been the practice to cut off from 60 to 75 pounds per ton of seed, as a first cut, for use in making mattresses; the remainder went into the meal used for cattle food. As a development of the war, it now seems entirely possible that the second cut, hull fiber or linters, from the cotton seed may be made available for use in paper making. Little can be said as yet about this source of raw material, as the first mills for its preparation in quantity are just beginning operation. From figures now at hand, several hundred tons per day may become available, if the experiment is a success. Just how, when, and where the paper maker will use it remains to be seen, and much depends on what can be done with it after the preparation problem is thoroughly worked out. It now seems likely, however, that its place will be as a substitute for soft cotton rags, such as thirds and blues.

80. Preliminary Treatment.—A brief outline of the present ideas as to how this material should be handled follows:

The seed is first thoroughly cleaned and all foreign dirt is removed; after which, the first cut is made, say of 75 pounds per ton of seed. The seed is then cut, and the kernels are separated from the hulls. The latter are treated in a steel attrition mill for the removal of the fiber, and the fiber and hull bran are separated by proper screening.

81. Cooking.—The next process is the cooking. The cooking liquor used is caustic soda, and a fairly high concentration is necessary, say about 20% on the weight of air-dry fiber. Experiments so far indicate that a high pressure is needed (about 80 to 100 pounds), and that considerable care must be taken to insure proper circulation of the liquor in the boiler. The cooking time depends largely upon how rapidly the digester can be brought up to temperature, and it will probably be found that 6 to 8 hours will be the right length of time.

Little can be said as yet with regard to the type of boiler that will be used for this work. To date, experiments have been largely with the soda-pulp digester. There are two difficulties to be overcome with the ordinary soda digester, however; the first is that of circulation of the cooking liquor, and the second is the difficulty of blowing the cook. Very few of the cooks of this material in the usual soda digester will blow clean.

How the further preparation will be carried out is also rather a question. The cooked fiber must be washed and bleached. It will probably not be possible to screen it as a part of its preparation because of the very nature of the fiber. This makes it all the more necessary that it be thoroughly cooked, so that the bleaching process may destroy all the seed-hull fragments that are left in, and which would make dirt in the paper. Several mills are said to be using hull fiber and linters with good results, but details of their methods are not available.

82. Use in Paper Making.—The use of this material on any extensive scale in the paper industry depends on two factors: first, whether it can be so handled by the paper makers that it will produce the same strength, tear, and folding endurance that are obtainable with soft rags; second, whether it can be profitably produced in competition with soft rags over a period of time.

83. Bagasse.—The crushed stalks of the sugar cane, known as **bagasse** or **begass**, have been proposed many times as a possible source of paper-making raw material, and this material has been tried out on several occasions. It is first run through the cutter, and is then cooked with caustic soda.

The pulp is easily reduced, and is readily washed and bleached. The yield of pulp from the dry stalk is very low, from 20% to 30%. This fact, together with the fact that it is generally rather dirty, and that it may usually be more economically used for fuel on the plantation, has made its use very limited. In characteristics, it resembles straw pulp rather closely. An interesting use of bagasse paper is in covering young plants. The cane, or pineapple, pierces the paper, while weeds are smothered, and moisture conserved.

84. Miscellaneous Fibers.—Almost any fibrous raw material can be used in the manufacture of paper; consequently, there are many other fibers, the preparation of which might be outlined. Most of these fibers are seldom, if ever, actually used in making paper, however, and the general method of preparation is applicable to all. First, clean the fiber thoroughly; then cook it with an alkali; then wash and bleach it, and it is ready to be made into paper. Among others, the following deserve mention; papyrus, ramie, China grass, New Zealand flax, saw grass, flax straw and the paper mulberry-tree fiber of the Japanese. Corn and cotton stalks have also received some attention in the United States; there is a possible field of usefulness for them as fillers. Corn stalk fibers are very similar to those of bagasse.

ESPARTO

By James Beveridge

HISTORY AND OCCURRENCE

85. History.—**Esparto** was introduced as a paper-making material and as a substitute for rags in 1856 by the late Mr. Thos. Routledge, a North of England paper manufacturer. Since then, it has found much favor in England and in other European countries, owing to the quality of the fiber it yields, which is specially suitable for the manufacture of high-class book or

printing papers and medium-class writing papers. Printing papers made from it are of a soft, impressionable nature, yielding clear impressions from type and blocks. It is largely due to this property that the printing and book papers of the highest class in England are so distinctive in character.

86. Where Grown.—The grass occurs in Spain and Northern Africa; it resembles in form a stout wire, tapering to a fine point at the upper end, and varying in length from 12 to 30 inches. Owing to the demand, attempts have been made to cultivate it; but it grows wild, covering large areas in close proximity to the sea coast, and is somewhat easily obtainable. It is pulled (not cut) and harvested by the natives, packed in large pressed bales, and shipped in this form. It differs in quality, according to locality and selection, its price being regulated accordingly. These qualities take the name of the district or Port from whence they are shipped, such as Tripoli, Sfax, Oran, Gabes, etc., in Northern Africa. The Spanish variety, however, is considered the best, although now very limited in quantity, and it commands the highest price. This grass is fine, of a bright russet-yellow color, free from the green chlorophyl when well matured, and yields the highest percentage of fiber. On the other hand, the varieties from Northern Africa differ widely. Some are green, coarse, and unripe, yielding a lower percentage of fiber, and are more difficult to reduce to pulp and to bleach. The additional expense incurred in this treatment naturally reacts on their market value. From whatever source obtained, it is recognized that the fine, well-matured, or ripe grass is more easily reduced to fiber than the coarse, green, and unripe variety; in that it requires less chemicals and yields more finished paper. Esparto should always be kept under cover in a dry place, as it is apt to heat and rot, if allowed to get wet.

Note.—**Esparto** (*Stipa tenacissima* and *Lygeum spartum*). The bast fibers are grouped in bundles or filaments, which are resolved into ultimate fibers by the chemical processes employed. The fibers are shorter and more even than those from straw, averaging about 1.5 mm. in length, and the central canal is nearly closed. Serrated cells are numerous, but are considerably smaller than those from straw, while the smooth, thin-walled cells are absent. The chief characteristic that distinguishes esparto from straw and other fibers is the presence of small, tear-shaped cells derived from the hairs on the surface of the leaves. Cross and Bevan give the following as the percentage of cellulose in air-dry esparto: Spanish, 58.0%; Tripoli, 46.3%; Arzew, 52.0%; Oran, 45.6%.

87. Steps of the Process.—The process of reducing it to fiber is a simple one, involving four operations: viz., (1) dusting; (2) boiling; (3) washing, pulping, and bleaching; (4) screening and making into laps. The equipment employed for these operations is: For (1), a willow or duster; for (2), an esparto boiler, specially constructed for the purpose; for (3), an ordinary half-stuff or a breaking-in engine of the Hollander type, provided with a drum washer; and, finally, for (4), screening equipment and presse pâte machine, for running off the bleached pulp into a thick sheet. In place of the Hollander, a pulping machine of cylindrical type is sometimes used; and, obviously, the fiber may be screened before or after bleaching.

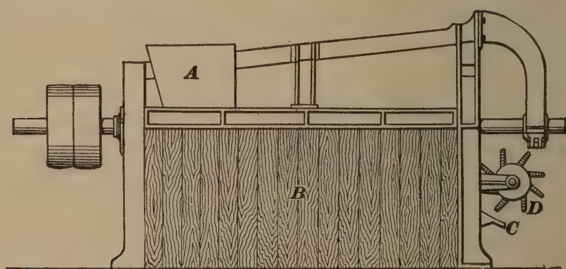


Fig. 16.

88. Dusting.—As the bales of esparto are brought into the mill, they are opened, and the grass is loosened and fed into the hopper *A*, Fig. 16, of the conical duster or willow. A conical screen revolves in a housing *B*, the sand and dust fall through, and the clean grass is discharged at the spout *C* onto a conveyor, which takes it to the loft over the esparto boilers. The paddle *D* keeps the spout clear. In the early days it was deemed necessary to remove all roots by hand picking, girls being stationed alongside the belt conveyor for this purpose; but as care is now taken to avoid pulling the roots while harvesting the grass, this precaution is considered unnecessary. The root ends of the grass are hard, and those that remain partly untouched by the caustic liquor during the cooking are removed by the screens. The loss in weight during the dusting varies from 1% to 6%; and the grass, after dusting, contains from 2% to 3.5% of mineral matter, the bulk of which consists of silica, which is soluble in sodium hydrate, and comes away in the black liquor as silicate of soda.

COOKING

89. Types of Digesters.—A form of digester in which the boiling takes place is shown in Fig. 17. It consists of an upright cylinder *M* with domed top, and fitted internally with a perforated false bottom *B*, from the center of which, a vomit pipe *C* receives the liquor that drains through and carries it upward, to pass again through the body of the grass. A steam jet *I* in the

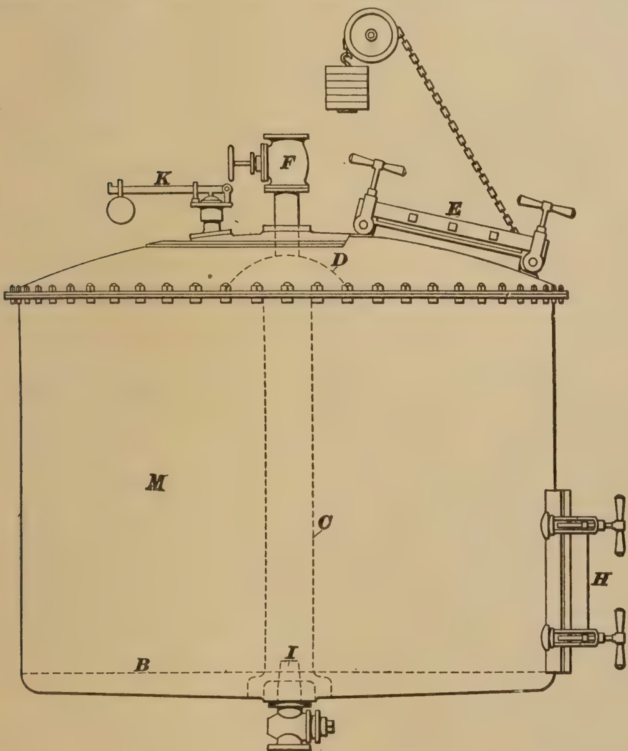


Fig. 17.

bottom of this vomit pipe, pointing upward, throws the caustic liquor against a dash plate *D* at the top, which distributes the lye over the surface of the grass. The boiler is also provided on its side with a circular door *H* immediately above the false bottom, to enable the workman to remove the cooked fiber, and with another door *E*, on the top crown, for the introduction of the grass. *K* is a safety valve, and *F* is a fitting for introducing cooking liquor and wash water, if desired. Liquor may also be run in through the charging hole.

90. A digester of a newer type, shown in Fig. 18, resembles the foregoing in its action. Two internal circulating, or vomit, pipes *A* are provided, one on each side of the vessel; these throw the liquor into the upper chambers *B* under the crown, and the liquor is then distributed over the surface of the grass, as shown in the illustration. Letters correspond to parts described for Fig. 17. Obviously, in place of the vomit pipes, a centrifugal pump may be used for circulating the liquor; and the boiler and its contents may be heated with a coil, instead of by injecting steam directly into the charge, in a manner similar to that sometimes employed in cooking wood pulp. These esparto boilers are built to hold from $2\frac{1}{2}$ to 3 tons of grass per charge.

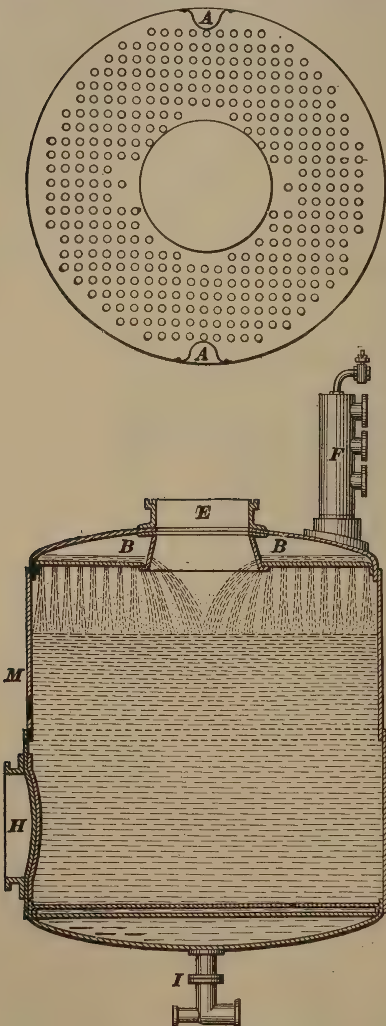


Fig. 18.

91. Cooking Liquor.—The stem of esparto (and of grasses in general) is largely cuto-cellulose or pecto-cellulose, instead of ligno-cellulose as in jute. This must be broken up by hydrolysis, and the non-cellulose substances, fats and waxes, rendered soluble. Some are changed to acids, which unite with the soda; others form sugars and other soluble substances.

The resolving fluid used is caustic soda (sodium hydrate), although the so-called sulphate processes, in which a mixture of sodium hydrate and sodium sulphide is used, is equally applicable. The caustic liquor is obtained by causticizing 58% soda ash with lime in the usual way (see the Section on *Soda Pulp*,

Vol. III), and the amount of alkali used varies with the quality and kind of grass and the treatment. For the finest quality of esparto, from 18 to 19 pounds of 58% alkali per 100 pounds of grass are enough; but for the coarsest immature kinds, as much as 25 pounds are required. These quantities of alkali, however, depend to a certain extent on the steam pressure (or temperature) and the time adopted for cooking. When high temperatures (or pressures) are used, less alkali is needed. The volume of lye used varies within somewhat narrow limits, and would depend on the quality of the steam and whether or not the charge is heated directly, with injected steam, or indirectly by means of a heating coil. As a general rule, it approximates to 95 cubic feet per 2000 pounds of grass in the former case; and, in the case of Spanish esparto, using 18 pounds of alkali per 100 pounds of grass, it would correspond to a liquor having a specific gravity of 1.048, at 62°F. (9.6° Twaddell), and would contain total alkali equivalent to 60 grams of soda per liter, of which 92% to 94% exists as hydrate, the other 8% to 6% being carbonate. When 25 pounds of 58% alkali are used, the liquor would have a specific gravity of approximately 1.066, at 62°F. (13.2° Tw.); it would contain soda equivalent to 84 grams per liter, of which from 92% to 94% exists as hydrate. The time required for cooking also varies, and depends on the amount of soda and the steam pressure or temperature; from 50 to 60 pounds pressure is common in modern esparto mills. At this pressure the average cooking time occupies from 2 to 3 hours.

92. Cooking Operation.—The following is a representative example of a cook in actual practice, in which fine, well matured esparto was treated, the amount of alkali required being 18 pounds (58% alkali) per 100 pounds of grass.

Esparto (Oran, fine ripe grass)	6000.0 lb.
Caustic liquor, volume	285.0 cu. ft.
Caustic liquor, Sp. Gr. (10°Tw.)	1.050
Caustic liquor, grams 58% alkali	60.0 per liter
Caustic liquor, grams soda (Na_2O)	34.8 per liter
Caustic liquor, per cent causticization	92.0 per cent
Time of boiling	$2\frac{1}{2}$ hours
Temperature	298°F.
Pressure (gauge)	50 lb.

93. To carry out this cooking operation in practice, the boiler is first of all filled with the loose grass, care being taken to

distribute it uniformly inside. The liquor is then run in, and the vomiting is begun. The caustic lye soon softens the esparto, causing it to fall and to pack somewhat closely on the perforated false bottom. As this takes place, more grass is added until the whole charge of 6000 pounds has been introduced. The main lid is then securely bolted down and the heating (and vomiting) is continued until the pressure reaches 50 pounds. During the heating, a little steam is allowed to escape, by means of a small valve provided for the purpose, to carry away the air and light oils inside. The pressure is maintained for $2\frac{1}{4}$ or $2\frac{1}{2}$ hours, after which it is blown down, the escaping steam being used for heating the next charge of caustic liquor, and, also the weak liquor for the first and second washings. When the pressure is nil, the black liquor is drained off, the hot washings from a previous operation are pumped in, and the vomiting is again begun. This strong wash liquor is run direct to the soda-recovery house and is mixed with the strong black lye. The recovery of the alkali in black liquors is fully treated in Vol. III, Sections 5 and 6. Hot water is now added, and the grass is washed a second time, the weak liquor from this washing being run off into a tank, to be used again as a first washing for the cook. The top manhole lid is now removed, and, if necessary, further wash water is added; but, as this will contain but a small quantity of soda, it may be run to waste. After draining thoroughly, the side door is opened, and the boiled grass is removed by hand into galvanized iron or wooden box trucks, or is otherwise conveyed, to the Hollander or bleaching engine. When properly boiled, the strands of grass will easily come apart, or will be broken up into pulp; in appearance, the original color of the grass will be preserved, but will be brightened.

WASHING AND BLEACHING

94. Operation.—Final washing and bleaching are usually carried out in one operation, in a Hollander of large capacity, fitted with drum washers, in order to remove the last traces of soda and some intercellular matter, which invariably passes away with the wash water. The bleach liquor, consisting of a solution of calcium hypochlorite $Ca(OCl)_2$, of a Sp. Gr. of 1.040 (or 8°Tw.) is then run in. In most cases the temperature is also raised to about 100°F., either by washing with hot water or

by direct heating with injected steam prior to bleaching. In this way, the bleaching is hastened. The fiber, after the addition of the bleach liquor, quickly changes color, if well-matured grass is being treated; but the color changes more slowly if the grass is green, always assuming that no great excess of bleach has been added. The pulp is kept in circulation for some hours; it is then dumped into a pulp chest, whence it is pumped to the screens *A*, which are usually placed at the end of the presse-pâte machine, Fig. 19. The screened stock passes to the flow box *B*, which delivers it in a quiet, shallow stream, over the apron *C* to the Fourdrinier wire *D*. Rubber deckle straps *E* prevent escape over the edges. Water drains through the wire, some is extracted by the suction boxes *F*, and some by the couch press (rolls) *G* and *H*. The sheet then passes to the felt *K*, which carries it through the press rolls *L* and *M* and delivers it at *N*, to carts or a conveyor. The fiber is run off on this machine as a thick web, and it is taken to storage or to the beating engines for conversion into paper. As a general rule, the fiber is bleached before screening, as this is considered a simpler method than that of screening before bleaching.

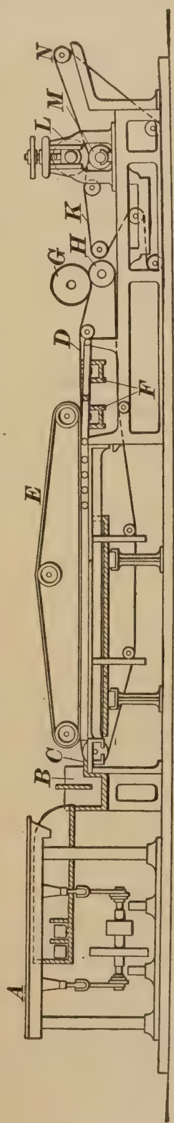


FIG. 19.

Consideration should here be given also to the wet machine, see Art. 59.

95. Yield Depends on Quality.—The yield of air-dry fiber containing 10% moisture, from 100 parts of grass, depends very largely upon the quality of the esparto. From well-matured Spanish and Oran, it does not exceed 45%, while in the case of the unripe or green kind it may be as low as 40 % or even under. Not more than 42% may be expected, on an average, from deliveries of North African grass.

96. The Sulphate Process.—Esparto fiber may also be prepared by the sulphate process, with equally good results.

The manufacturing conditions being very similar to the foregoing, as outlined for caustic soda. For details see Section 6, Vol. III, *Manufacture of Sulphate Pulp*. The advantages claimed for the sulphate method are: (1) A greater yield of bleached fiber; (2) a greater preservation of its strength. The treatment as a whole is also cheaper, salt cake being used in place of soda ash.

STRAW PULP

97. Kinds of Straw Pulp.—There are two kinds of straw pulp manufactured, viz.: (1) **Yellow pulp,** used for the production of cheap wrapping papers, corrugated papers, paper tubes, cans, straw boards, etc.; (2) **straw cellulose,** invariably marketed in the bleached state, and used for making the finest writing papers.

NOTE.—**Straw.** In straw pulp, the bast cells or fibers form the greater part of the pulp. These are comparatively short and slender, with sharp pointed ends; at quite regular intervals the walls appear to be thickened and drawn together to resemble joints. The dimensions of straw fibers vary with the kind of straw and with the conditions of growth, nature of soil, etc. They are longer than those from esparto, but not so long as the fibers from spruce wood, and would compare more nearly with poplar fiber in paper-making value. Accompanying the bast fibers in straw pulp are numerous epidermal cells from the pithy portion of the stem. (See Fig. 1, Section 1, Vol. III.) The latter vary in shape from nearly round to long, oval cells, whose length is several times their width. Both types of cell aid materially in the identification of straw pulp.

Straw as used in paper making includes the stems and leaves of the various cereals. The composition of straws, particularly with regard to the amount of ash and its constituents, varies greatly with the soil upon which they were grown. Wolff gives the following analyses for different straws:

	Winter rye, %	Winter wheat, %	Summer barley, %	Winter barley, %	Oats, %	Corn, %
Water	14.3	14.2	14.3	14.3	14.3	14.0
Ash	3.2	5.5	7.0	5.5	5.5	4.0
Fat and wax	1.3	1.5	1.4	1.4	1.4	1.1
Nitrogenous matter	1.5	2.0	3.0	2.0	2.5	3.0
Starch, sugar, gums, etc.	25.7	28.7	31.3	28.4	36.2	37.9
Cellulose	54.0	48.0	43.0	48.4	40.0	40.0

See also Lloyd, "The Structure of Cereal Straws," *Pulp and Paper Magazine of Canada*, Vol. xix, pages 953-4, 973-6, 1002-4, 1025-6, 1048-50, 1071-5 (1921).

98. Yellow Straw Pulp.—From the storage piles, the bales are taken by a slat conveyor to the charging floor of the rotary house, the baling wires having been removed. Spherical rotary boilers (see Fig. 8) are generally used; these are loaded with straw, without any preparation, through the manhole, by hoppers placed in holes in the charging floor. The straw is loaded by forks, and is rammed down as compactly as possible by hand, with a long, heavy rod having sharp prongs.

Because of its bulk, it is impossible to fill the rotary with the loosened straw in one operation; hence, charging in stages, or **wilts,** is necessary. The combined action of the lime water and heat, in the *wilting*, causes the straw to settle and pack together. See cooking cycle, Art. **103.**

99. The milk of lime is prepared in a tank, equipped with an agitator, the lime being placed in a perforated basket at the top. The tank has a capacity of 2000 to 2500 U. S. gal., depending on the size of the straw charge and the volume of water used. The strong milk of lime is dropped into a second tank, where the necessary additional water is added. Steam coils may be used in this tank for keeping the liquor hot, which is required for obtaining the most efficient operation. The liquor is elevated by a pump or steam siphon to the charging floor, where it is added to the rotary by swinging pipes.

After the cooking is finished, the steam pressure is released,—called **gassing down,**—and the rotary is dumped to the drainer pit, or into conveyors leading to it. The drainer pit floor is usually of concrete, and it slopes toward drains covered with perforated iron plates; these serve to carry off the excess liquor, which drains away while the pulp is seasoning. *Seasoning*, which takes two days whenever possible, is thought to allow for completion of all action by the lime. The pulp becomes darker, somewhat softer, and gains a stronger odor. The drainer pit also acts as a pulp storage. *In well cooked pulp, there is very little excess liquor.*

In the more modern mills, the pulp is now put into **breaker beaters.** These are equipped with a continuous beating, or extracting, device, such as the Griley-Unkle, Shartle, etc. Properly cooked straw forms into balls when dumped from the rotary; the breaking operation breaks up these balls, reduces the straw to comparatively short lengths, and loosens up the lime from the fiber, with the result that there is quicker beating and washing.

Some breaker beaters are equipped with washers, which remove some of the lime. From the breaker beaters, the pulp goes to the beaters, where the beating and washing are completed.

100. Kinds of Straw Used.—*Wheat* and *rye straws* are the best—they give the stiffness desired in corrugating paper, which must withstand crushing strains. *Oat straw* makes softer pulp, although good corrugating paper is made from it; it is also very suitable for thick boards. *Rice straw* has been found to be too short-fibered to afford sufficient strength. *Barley straw* is not suitable, being too soft fibered and too short.

The straw must not be rotten, since this will result in tender pulp, which will not stand up under beating and jordaning. Straw should contain as little chaff and non-fibrous matter as possible, and should not be too wet. Wet straw can be used, but it should be mixed with larger amounts of dry straw. When using wet straw, more lime and less water must be used in the cooking liquor, in order to maintain the liquor concentration and the proper penetration of the lime into the fiber.

Clippings from corrugating machines (corrugated clippings) are used to some extent, and in times of straw shortage, ordinary mixed papers are added in small amounts. Both of these materials give a softer and more flexible sheet, which is not so desirable for the corrugating operation.

101. Preliminary Treatment.—No preliminary treatment of the straw is necessary. In properly cooked straw pulp, the knots, or nodes, are so softened that they can be crushed between the thumb and finger, this index being the customary guide to proper cooking. Such pulp easily reduces in length in the breakers and beaters, and no preliminary cutting is practised. Dusting is likewise unnecessary.

102. Cooking Practice.—A typical cooking cycle for straw pulp for corrugating paper is given herewith.

Straw pulp for corrugating papers must be more "raw" and harsh than that for straw boards, egg-case stock, etc., in order to give the stiffness required to resist crushing of the corrugations. Straw pulp for boards is cooked from 10 to 12 hours, at 40–45 lb. per sq. in. steam pressure; and the knots, after dumping, are considerably softer than in pulp for corrugating paper. The amount of lime used is generally the same. Some mills use

rotary charges of 6 to 6½ tons; but because of the time required to fill, these make but one cook per 24 hours.

High calcium lime is more generally used than magnesium lime or dolomite, as its action is quicker and more intense. For this reason, when dolomite is used, a larger amount is needed than when calcium lime is used. In the cycle here given, 180 lb. of calcium lime is used per ton of straw. It would be necessary to use 240 lb. of dolomite, testing 42% MgO, per ton of straw to get the same result.

103. Because of the intense action of *calcium lime*, it tends to spend itself on the first straw it touches, thus making it overcooked or burnt, and leaving the remainder undercooked. When all the lime is added at the start of filling, the last fills are added

12-Hour Cycle, Straw Pulp for Corrugating Paper. Two Cooks per Day per 14-Ft. Dia. Rotary

Operation	Material	Amount	Time	Remarks
Charging: (rotary not running)	Straw	100 bales	0.5 hr.	
First fill	Wheat and rye	3.15 tons		
	Half of liquor			
	Water	120 cu. ft.	As milk of lime, hot. Lime to test a minimum of 80 % CaO.	
	Lime	450 lb.		
First wilt	Steam	25 lb. gauge	1.0 hr.	
Second fill	Straw	40 bales	20 min.	
		1.56 tons		
Second wilt	Steam	25 lb. gauge	30 min.	
Third fill	Straw	20 bales	10 min.	
	Second half of liquor (same as for first fill)	0.63 tons		
Third wilt	Steam	25 lb. gauge	20 min.	
Totals for filled rotary:				
	Straw	160 bales		
		5.0 tons		
	Water	240 cu. ft.		
		1800 U. S. gal.		
	Lime	900 lb.		
	Time		3 hr.	
Cooking: (rotary running)				
	Steam	40–50 lb.	7 hr.	
		Not less		
Gassing down: Steam pressure release (rotary not running)				
		40–45 lb. to 0 lb.	¼–½ hr.	
Dumping (rotary running)				
			1½–1¾ hr.	
Total time	....	....	12 hr.	

so long after the lime is introduced that the cooks tend to be uneven and too raw, the strength of the milk of lime being then considerably reduced. For this reason, it is preferable to add the milk of lime in two parts (halves), as in the cycle given. The last straw added is then acted on by fresh lime, and a more evenly cooked pulp is obtained. The best method is to fill the rotary with hot water and add the lime, as a strong solution, after all the straw is charged. In this way, all the straw is treated alike.

Care must be taken that the lime is completely slaked, especially when dolomite is used, which is slower slaking. The progress of each cook should be recorded by a steam-flow meter or pressure gauge, and the steam pressure should be as constant as possible. A pressure regulating valve is desirable. Straw is not usually weighed into the rotaries, but is added as so many bales. To secure uniform weight of charge, it is necessary that straw be purchased in bales of uniform weight and size.

In some mills, a little steam is turned on while forking and ramming the straw into the rotaries; this assists in wilting. It is also the practice to shut off the steam two or three hours before the end of the cook, and let the rotary roll without fresh steam. The essential thing is to maintain the proper temperature, which for 40–45 lb. gauge pressure is about 290°F.

104. Rotaries.—As previously stated, the digesters used are almost invariably of the spherical rotary type. The usual size is 14 ft. in diameter, and having a maximum capacity of 7 tons of dry straw. These revolve on trunnions, and are provided with suitable manholes and covers, with gaskets, for filling and emptying. Steam is passed into the digester through the trunnion.

In the usual construction, shown in Fig. 8, if by any chance the straw should not be entirely surrounded by liquor at the point of entry of the steam, there is a possibility of the straw burning. A valve-box or steam-chest arrangement is used in some mills to avoid this, the steam entering only through pipes at the bottom of the rotary, and thus coming into contact with the straw through the liquor. Pins inserted on the inside around the circumference, are of advantage; they tend to produce more evenly cooked pulp by preventing the sliding of large masses of straw. A clutch is used for starting and stopping the rotary, to save time in placing the manhole in proper position for filling.

Some attempts have been made to insulate rotaries against heat losses, but these have not proved successful.

A rotary requires about 3 h.p. to operate it. The bale conveyor from the yard to and along the charging floor, and the conveyor for taking cooked straw to the drainer pit, require about 2 h.p. per ton of pulp produced per 24 hours.

105. Yield.—One ton of dry wheat and rye straw yields, after washing, about 70% of pulp ready for refining. Straw carries little but siliceous inter-cellular material, which is considered, for practical purposes, as pure silica. The main effect produced by the cooking process is that of loosening the silica, with the formation of calcium silicate. The fiber is thus freed of inter-cellular material, and may be washed clean of most of the residue.

106. Breaking, Beating, and Washing.—Beaters, and breaker beaters (when used), are equipped with at least two drum washers, having 40- or 44-mesh wire cloth, with heavy, coarse backing wire. Perforated metal has been tried, but has less hole area, thus making the washing operation longer. For best results, the washing and beating require 4 hours. The roll is first lowered to about 1 inch from the bed-plate; this allows for any lumps to become completely broken up and the stock to become "straightened out." The roll is run at ½ inch from the plate for 10 or 15 minutes; and at intervals of 10 or 15 minutes thereafter, it is lowered a little, until it comes to a good brush. If lowered too quickly, the lime will be driven into the fiber before it can be washed out. The roll should never ride on the plate, since the straw will then be cut too short. The straw is considered beaten when it is about 1 inch long, but not much less than this.

Washing and beating take place simultaneously, the washing water being turned on as soon as the beater is furnished. The wash water is best added to the stock through a sprinkler pipe in front of the roll; this causes good mixing of water and stock as it goes under the roll, and results in faster washing. If the paper-machine white water is pumped directly to the beaters, i.e., not held in tanks, it can be used both for beater make-up water and for washing: its retention in tanks causes much slime formation. It has been found possible to make straw paper with 14,000 U. S. gal. per ton, total water. The washings are sent to the sewer.

Washer wires clog quickly; they must be frequently washed free of lime, using weak muriatic (hydrochloric) acid. The washer

dippers, shutters, and internal parts must also be cleaned regularly with acid,—at least once every three months,—or the efficiency of the washers will be seriously reduced. The washing is considered complete when a handful of stock taken from the beater and squeezed, shows the water clear; if it is yellow, too much lime is still present. The stock also loses its gritty feel when well washed. The stock is beaten an hour or so at a good brush; and if washing be then completed, the roll is raised until the beater is dumped.

Stock should run fairly thick in the beaters. Thick stock presses better against the washer wires, which facilitates the washing. It is necessary to use kerosene liberally when washing, to reduce foam. Drainer-pit pulp runs about 23% ash. It is not possible to remove all of the lime by washing; hence, washing beyond a certain time is useless. After washing 2 hours, 14.5% ash is left in the fiber, and washing another hour reduces this only to 13.6%, or practically no further removal of ash.

Corrugated, heat-treated fly-bars are very good. Bed-plates are preferably of the elbow type, but not too fast cutting and of softer steel than the fly-bars. Bed-plate bars are easier to replace than fly-bars, and if softer, they will take the wear rather than the fly-bars. Straight fly-bars are also extensively used.

107. Refining.—Straw pulp for corrugating purposes must be well jordaned. The usual practice is to pass it through two or three jordans in series, and to subject the stock to all the power possible. The stock at the machine must be short enough to form a well closed, stiff sheet.

108. Bamboo.—The enormous quantity of bamboo in the world, and its very rapid growth, makes this peculiar grass a promising source of paper-making material. The need for its exploitation is in sight: years of research by Raitt and others have shown the feasibility of preparing bamboo pulp by the soda or the sulphate process. Indian bamboo contains 50% to 54% cellulose, and Philippine bamboo contains slightly more. Raitt found the soda process to yield 41% to 43% of bleached pulp suitable for high-grade papers. The sulphate process gives about 1% higher yield, with considerably less bleach—15.5% to 18%. The sulphite process is unsuited, because of the amount of silica in the plant and the difficulty in maintaining a strong bisulphite liquor in the tropics. See *Indian Forest Records*, Vol. 3, Part 3.

Raitt recommends that (1) only shoots be cut that have attained the full season's growth; (2) that the culms be seasoned at least 3 months before use; (3) that it be crushed; (4) that the starchy matters be extracted; and (5) that the sulphate process be used.

Satisfactory digestion of the five species investigated was found to be possible with 20% to 22% caustic (hydrate and sulphide), temperature 162° to 177°C., pressure 80 to 120 lb. per sq. in., and 5 to 6 hours' cooking time.

NOTE.—**Bamboo.** Bamboo fibers closely resemble those from the straws in many of their characteristics. According to Raitt, the average length of the ultimate fibers is from 2.20 to 2.60 mm. according to the variety, and diameters are from 0.018 to 0.027 mm. While not so long as spruce fibers, they are much longer than those from any of the deciduous trees.

PREPARATION OF RAG AND OTHER FIBERS

EXAMINATION QUESTIONS

(1) When and where were rags first used for making paper?

(2) What kinds of rags are used for (*a*) writing paper? (*b*) wrapping paper? (*c*) roofing paper?

(3) In purchasing rags, what materials would you limit or exclude?

(4) Describe the rag thrasher, and tell what it does.

(5) Why and how are rags sorted?

(6) Describe the apparatus and the process of cutting rags.

(7) What is accomplished in the cooking of rags?

(8) Describe one type of rag boiler.

(9) Explain the filling of the boiler and the cooking and emptying.

(10) Name the variable factors in cooking, and state how a change in each one affects the others.

(11) (*a*) Explain what happens to the rags while washing; (*b*) how long does this take, and how much water is used?

(12) Why are rags bleached?

(13) How is the bleach liquor prepared for bleaching rags?

(14) Express your opinion of a foreman who used 12% of bleach for Thirds and Blues and added a chemical to neutralize the excess.

(15) (*a*) What are the items of loss in preparing rags? (*b*) how do these vary with different classes of rags?

(16) What kinds of paper are made from manila hemp?

(17) How does jute differ from other fibers herein considered?

(18) (*a*) What is the source of esparto? (*b*) for what papers is it used?

(19) (*a*) How is yellow straw pulp prepared? (*b*) what is the average yield?

(20) (*a*) What is the practical test used to tell whether straw pulp is properly cooked? (*b*) how are the breaking, beating, and washing operations conducted?

SECTION 2

TREATMENT OF WASTE PAPERS

BY ED. T. A. COUGHLIN, B. S., CH. E.

USE, VALUE, RECOVERY, AND GRADING

USE AND VALUE OF WASTE PAPERS

1. Reasons for Extensive Use of Waste Papers.—The use of printed waste paper, or *old paper stock*, as it is commonly called in the mill, has developed to such an extent on this continent that it rivals, even surpasses in some cases, the use of soda and sulphite pulps in certain grades of paper. There are many reasons why old paper stock has reached this point of importance, some of which are: the immense available supply of material; the low cost of material; low cost of converting into paper pulp; desirability of the converted product.

2. At the present time, old paper stock is employed in the manufacture of container board, box board, wall board, leather board, papier-mâché, roofing paper, manilas, carpet paper, wrapping paper, bag paper and printing papers. In the finer grades of paper, such as book and printing paper, body stock of coated paper, lithograph and book papers, the cheaper grades of writing, mimeograph, offset, drawing, bible, blotting, map, parchment, music, catalog, tissue, water leaf and cover papers, the percentage of old paper stock used in them ranges from 10% to 80% of the furnish.

3. It would be difficult to ascertain the limits of the field for consumption of old paper stock. This material, when properly de-fibered and freed from colors, dirt and ink, can be safely used in all but the finest grades of writing and record papers, and in papers that call for a specially long fiber, where the

composition of the sheet to be made has been specified previously. Consequently, it is not strange that what formerly was a waste and a useless commodity now finds a ready application to almost every grade of paper made.

By far the largest tonnage of this waste-paper material is re-made into boards, liners and newsprint; in fact, it has been estimated that about 10,000 tons of old paper stock is daily re-made into the classes of paper here mentioned, and about 2500 tons is employed daily in the manufacture of book, writing and the other grades of the better class previously referred to. This Section will deal more particularly with this latter application of the great American waste.

As a subject for discussion, "The Reclamation of Printed Waste Paper" has been almost as popular a theme as "A New Substitute for Wood Pulp." For years, it has been the goal of many determined paper makers, of many enterprising business men, also of many adventurous fakers, to work over old magazines, books, letters and bill heads, and even old newspapers, in such a manner as to produce a grade of paper equal in every respect to the original. Many machines have been devised, and many processes have been worked out in secret, to re-pulp and de-ink discarded paper, but a large proportion has resulted in economic failures. Notwithstanding quite extensive skepticism concerning the practicability of the process, thousands of tons of paper are daily being re-made into high-class book and printing papers and similar grades, which compete with, and sometimes quite materially undersell, the pure-fiber papers.

4. Value of Waste Paper.—A more general appreciation of the market value of rags, rope, and waste paper of all kinds, would increase largely the supply of old paper stock; it would also add considerably to the income of the general public. According to figures for 1919 by the U. S. Department of Census, rags to the value of $23,000,000 were used in that year for paper making, besides $7,000,000 of rope, jute bagging, waste, threads, etc., while several times this amount could be secured under proper collecting conditions. Waste paper to the value of $43,000,000 was used in 1919 in paper making, and it is estimated that three times this amount could be made available. Even though 1919 was a period of high prices, it is therefore evident that the value of the waste paper annually destroyed is very great; if reclaimed and used, it would serve a double purpose—the production of

good paper, and the conservation of the material, largely wood, that the waste paper replaces. The 1,000,000 tons of paper now wasted each year, and which could be saved, would make all the building, bagging, cover, blotting and miscellaneous papers, and all the paper board, that is now produced.

Considering, then, the immensity of the field and the profits to be derived, it is only logical that many methods should have been devised and patented for reclaiming old paper stock.

METHODS OF RECOVERY

5. Classification of Methods.—It would be almost an impossibility to collect and record all the different methods that have been patented. Those processes that are in practical use in the mills will be considered in detail. The methods are here treated under three heads: mechanical action alone, without the use of chemicals; chemical action alone; combined mechanical and chemical action. For each class, many processes, and the equipment therefor, have been patented. Some of these show a lack of knowledge or experience regarding their practical, economical operation. It may be remarked that few branches of the paper industry have brought out more patents than this.

6. Mechanical Processes.—Very few methods of any value are to be found in the class that includes the processes grouped under mechanical action alone; for, to produce a good white pulp for book paper, it is necessary that the inks be entirely removed. Printing inks consist mainly of some pigment, which is combined with an oil or varnish body, called the *vehicle.* To remove the ink, saponification by an alkali of some kind is necessary, in order to effect a combination of the alkali with the vehicle and free the pigment. However, under mechanical action alone may be classed all methods employed in roofing and board mills that use only old newspapers, wrapping papers, and box boards. For the grade of paper there produced, the color is of secondary importance, and the products are usually heavily colored with loading ochers and red oxides.

7. Chemical Processes.—Treatment of papers by chemical action alone is understood to refer to those processes in which the papers remain stationary, the liquor used being allowed to circulate and permeate the mass thoroughly. In this way, the

ink is broken up, being deprived of its vehicle, and it is easily washed out subsequently in the washing engines. This method is the practical outcome of the earliest experiments in treating waste papers; it is called the *open-tank cooking process,* and it is still largely in vogue in mills of the Middle West.

8. The first description of a process of this type is credited to J. T. Ryan, of Ohio, and was patented by him. After being dusted, the papers are cooked with a soda-ash solution of 5°Be. at 160°F.

In the method patented by Horace M. Bell and Edmund R. Lape, of Swanton, Vt., the dusted papers are agitated in a solution of 1 part soap and 600 parts water for each 10 parts of papers; the loosened ink is then washed away.

9. Combined Mechanical and Chemical Processes.—By far the greatest number of actual and proposed methods depend on the combined chemical and mechanical treatment of the papers; the most important of these is the rotary-boiler process, the details of which will be thoroughly discussed later. The cooking-engine process, and several other patented processes will also be considered in detail.

10. John M. Burby states, in U. S. patent No. 1,112,887, that alkalis are most suitable for use as solvents in processes for the recovery of pulp from printed waste papers; but, if they are used in solutions containing more than the equivalent of 2 parts of caustic soda to 1000 parts of water, or if weaker solutions are employed at a temperature of 150°F. or higher, they produce a discoloring effect on the mechanical wood pulp that may be contained in such waste papers. Mr. Burby found that a solution of 1 part (or even less than 1 part) of caustic soda, measured by weight, in 1000 parts of water, if employed in proportionate quantities, is sufficient in most cases to counteract the adhesiveness of the oily medium of printer's ink. Other alkalis may be used in place of caustic soda.

CLASSIFICATION OF WASTE PAPERS

11. Grades of Papers.—Until recently, no definite standards or distinct classes were deemed to be necessary in the classification of waste papers. Perhaps the first distinctions made were: (*a*) Waste papers for No. 1 stock, such as shavings and cuttings

of papers not printed upon and which could be used directly in the beater without preliminary treatment; (*b*) waste papers for book stock, which comprises practically all kinds of printed matter except groundwood, or mechanical, pulp papers; (*c*) all other waste papers, which are made into cheap box board.

12. Quite naturally, paper manufacturers using these wastes, especially book-paper men, noticed that certain grades of paper produced a cleaner and more uniform sheet, and they therefore discriminated in their selection of stock; this has resulted in the following grades of waste papers, with their prices per 100 lb., the latter fluctuating according to the season and to the demand:

Quotations on Waste Paper	Oct., 1915	Oct., 1922
No. 1 hard white shavings	\$2.40 –2.50	\$4.20–4.40
No. 2 hard white shavings	2.00 –2.10	3.75–4.15
Ledger, solid books	1.75 –1.85	3.00–3.25
No. 1 soft white shavings	1.75 –1.80	3.75–3.90
Ledger stock	1.40 –1.50	2.70–2.80
Magazine, flat	0.80 –0.90	2.45–2.50
Magazine, unstitched, flat	0.95 –1.00	2.65–2.70
Crumpled book stock	0.70 –0.75	2.10–2.15
White blank news	1.05 –1.10	2.00–2.15
New manila envelope cuttings	1.50 –1.60	2.50–2.60
New manilas	1.30 –1.40	2.00–2.10
Manilas, extra	0.90 –1.00	1.80–1.90
Manilas, No. 1	0.65 –0.75	1.50–1.60
Manilas, No. 2	0.35 –0.45	1.40–1.50
Bogus wrappers	$0.42\frac{1}{2}$–0.45	1.10–1.20
No. 1 mixed papers	0.30 –0.35	1.05–1.15
Ordinary mixed papers	0.25 –0.30	0.80–0.90
Over-issues	0.50 –0.55	1.20–1.25
Folded news	0.35 –0.40	1.25–1.35
Box maker's cuttings	0.30 –0.35	1.05–1.15
Telephone books	0.25 –0.30	0.55–0.65

Even with these distinct grades, the mills are continually being annoyed with shipments that do not approach the quality specified in the orders. If there is to be any profit at all, it is practically impossible for the original packers to grade so closely that the stock can be used without subsequent mill sorting, particularly in the case of magazine, book, and mixed ledger grades. In these items, an allowance of 3% for groundwood is made to the packers; all over this amount is deducted from the original price of the stock, and is paid for as "print." In magazine stock, an allowance of 3% is made for any book stock that may be

found on sorting; if a greater percentage is found, it is paid for as ordinary book stock. Similar allowances are made in mixed ledger stock, which is very hard to grade.

WASTE-PAPER STANDARDS AND PRICE FLUCTUATION

13. A Satisfactory Standard.—For a long time, there was considerable difference of opinion as to how to grade a paper over which there was a controversy regarding its correct classification. No set standards were in general use among packers until the Theodore Hofeller Company, of Buffalo, N. Y., issued a set of standards, which were found to be satisfactory to all the trade. This classification is as follows:

14. No. 1 Book and Magazine Stock.—No. 1 books and magazines must be free from groundwood paper, parchment paper, magazine covers made of dark-colored paper, school paper, paper shavings, photogravure paper, and free from books with burned edges. The following are some of the books and magazines that will not be accepted as No. 1 books and magazines: Ainslee's, All Story, Blue Book, The Cavalier, Pearson's, Popular, Red Book, Top Notch, Short Stories, catalogues from mail order houses, cheap novels, telephone books, etc. Thick books, approximating the size of Dun's Agency books, should be ripped apart, making each part the thickness of an ordinary magazine.

15. Ledger Stock.—Ledger stock consists of high-class writing paper, account books, ledgers, letters, checks, bonds, insurance policies, legal documents, etc. The paper may be white or tinted, it may be torn into two or three parts, but it must not be torn into small pieces. Covers must be removed from books and ledgers. The following will not be accepted as ledger stock: Postal cards, school papers, telegrams, envelopes, parchment paper, tissue paper, copying books, manila paper, colored paper, railroad bills of lading, freight bills, ledgers or books with burned edges.

16. Mixed Paper Stock.—Mixed paper consists of clean, dry paper from stores, offices, schools, etc. It may include wrapping paper, cardboard boxes, paper book covers, pamphlets, No. 2 book stock, telephone books, crumpled newspapers, envelopes and paper torn into small pieces that is not good enough for book stock or ledger stock. The paper must be free from excelsior, sticks of wood, rubbish, iron, strings, rags, leather or cloth

book covers, free, in fact, from all material that cannot be manufactured into paper. Bricks, concrete, and even dead cats have been found in waste papers.

17. NEWSPRINT STOCK.—Folded newspapers must be clean, dry, flat, folded newspapers, such as come from private homes, newspaper offices, news stands, libraries, etc. Pamphlets, mixed papers, and crumpled newspapers, will not be accepted as folded news.

18. Subdivisions of Standard Grades.—In book-paper mills, there is a considerable variety in the grades of paper made; as a consequence, a difference in the quality of old papers used in the furnish is called for. Most mills have only two grades, which they call No. 1 and No. 2. The **No. 1 grade** is made up chiefly from ledger stock, for solid ledger books from a very fine sheet. The **No. 2 grade** is made from magazines and books; and, although a good sheet can be made from this stock, it does not, of course, command a price as good as that made from No. 1. These two grades are sometimes further subdivided by calling the paper made from them **Extra No. 1** or **No. 2,** and **Special No. 1** or **No. 2.** This difference is created by the use of high-grade ledgers and No. 1 school books, or by a variation in the pulps used.

The European classification of waste papers, given in the French edition of this book, differs somewhat from the American classification.

19. Another Standard Classification.—The following Standard Classification for Waste Paper has been adopted by the National Association of Waste Material Dealers to be effective from July 1, 1922, to July 1, 1923.

BALING. Unless otherwise specified, it is understood that all grades are to be in machine pressed bales.

TARE. It is understood that unless otherwise specified, tare shall not exceed 3%.

WEIGHTS AND QUANTITIES. A carload, unless otherwise designated, shall consist of the weight governing the minimum carload weight, at the lowest carload rate of freight, in the territory in which the seller is located.

HARD WHITE ENVELOPE CUTTINGS. Shall consist of all white, hard-sized (writing) papers, to be free of groundwood, ink and all foreign substances.

HARD WHITE SHAVINGS. Shall consist of hard-sized, white writing paper, free from colors and tints, groundwood, and other substances. May contain machine-ruled and unruled paper but not print-ruled.

SOFT WHITE SHAVINGS. Shall consist of all white book-paper cuttings, free from groundwood, ink, colors, and not to contain over 10% of coated papers.

No. 1 HEAVY BOOKS AND MAGAZINES. Shall contain all books and magazines, which are to be free of crumpled and scrap papers, and shall not contain to exceed 3% of groundwood, leather, cloth and board covers.

Mixed Books and Magazines. Shall consist of magazines and books, to be free from all other kinds of paper. They must not contain more than 20% groundwood papers, leather, board and cloth covers and foreign substances.

Kraft Papers. Shall contain all kraft papers, free of waterproof papers.

No. 1 Print Manilas. Shall be composed of a majority of manila colored papers, writing papers and office waste. It must be free of soft papers, news and box board cuttings.

Container Manilas. Shall consist of manila and other strong papers, with soft papers such as news and box board papers eliminated.

Newspapers. Shall contain dry, clean newspapers, free from all foreign substances not suitable for the manufacture of paper.

Mixed Papers. Shall consist of all grades of dry waste paper, free from objectionable material or materials that cannot be manufactured into paper.

Note. Variations of the above grades or grades not included in this classification are to be sold by description and sample or by sample.

20. Price Fluctuation.—The fluctuation in the prices of the different grades of waste papers presents an interesting study; it is a direct indicator of conditions among the mills. For instance, the price of No. 1 magazine stock varied from $0.60 to $0.90 in 1911, and from $0.75 to $1.10 in 1907; these figures include the highest and lowest prices in the years 1907 to 1912. These figures are quoted for the years given because the prices in the war years do not represent normal conditions.

Variation in price is due to the law of supply and demand, and is also influenced by the seasons. In the spring and summer months, the collections increase, and the supply on hand with the packers increases to such an extent that storage costs necessitate a quick and ready market; as a result, the price naturally drops. In the fall and winter months, the mills having stocked up to full capacity, the demand for paper stock lessens; but, by reason of the increased cost of collecting, the prices usually increase. However, the price of the higher grades of ledger and shavings is not so flexible; the price of these is governed mainly by the available supply, and by the ruling price of the rags or bleached sulphite that enters into the manufacture of new paper.

QUESTIONS

(1) Compared with the total supply available, what is the probable proportion of waste paper collected?

(2) Under what classification can the processes of treating waste papers be placed?

(3) What is the nature of printing ink, and what chemical action is usually necessary to get rid of it?

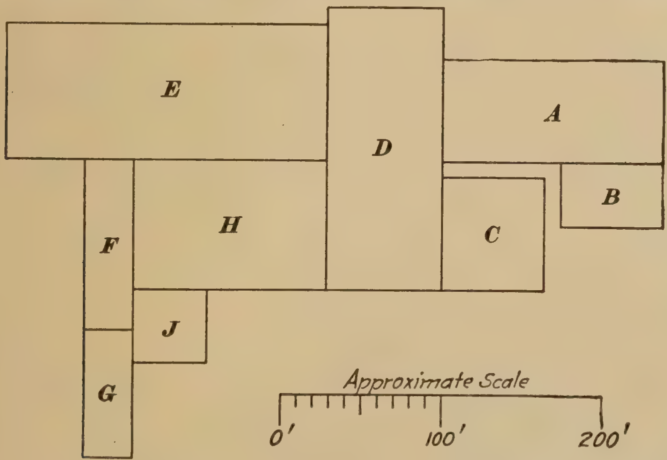
(4) Name a class of papers for the manufacture of which chemical treatment of the waste paper used is not required, and state why.

(5) On what basis are waste papers classified?

SORTING, DUSTING AND SHREDDING

MILL SORTING

21. General Layout of Mill and Sorting Rooms.—The general plan, or layout, of old-paper sorting rooms is practically the same in all mills. The sorting rooms are usually situated in a comparatively isolated part of the mill, to avoid getting dirt in the finished paper; they are generally on the top floor of the mill, so the papers can be delivered by gravity to the cooking



Bldg.	Construction	Purpose
A	4 Stories and basement	Paper storage and sorting
B	4 Stories and basement	Paper storage, cutting and dusting
C	2 Stories and basement	Cooking building
D	1 Story and basement	Beater room
E	1 Story and basement	Machine room
F	1 Story and basement	Finishing room
G	1 Story and basement	Packing and shipping room
H	1 Story and basement	Power plant
J	1 Story and basement	Repair shop

Fig. 1.

or bleacher room. This arrangement causes the various steps to be progressive, in the course of manufacture, and makes the process continuous. A glance at Fig. 1, which is a plan of the mill, will make this clear.

The sorting room must be well lighted and ventilated, since light is essential for close sorting; and the dust-laden air must be continuously removed, to preserve the health of the sorters. A diagram giving the general sequence of the various operations is shown in Fig. 2.

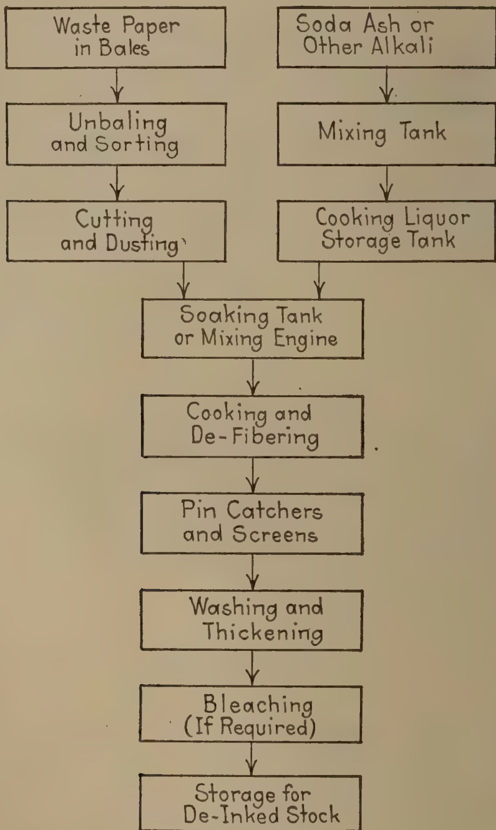


FIG. 2.

BENCH SYSTEM OF SORTING

22. Description of Bench System.—When the waste papers reach the mill, they are weighed in by the storehouse foreman, and the weight is written on a tag, which is securely fastened to the bale. If there is room for it, the stock is placed on a car, sent up on an elevator to the sorting room, and run alongside

the benches, if the sorting room is well supplied with them; after the car has been unloaded, the stock is placed in the storehouse, in numbered bays. The storehouse foreman of a book-paper mill is well qualified to judge the quality of the stock as it comes to him; and if he thinks it will run excessively to print or discards,

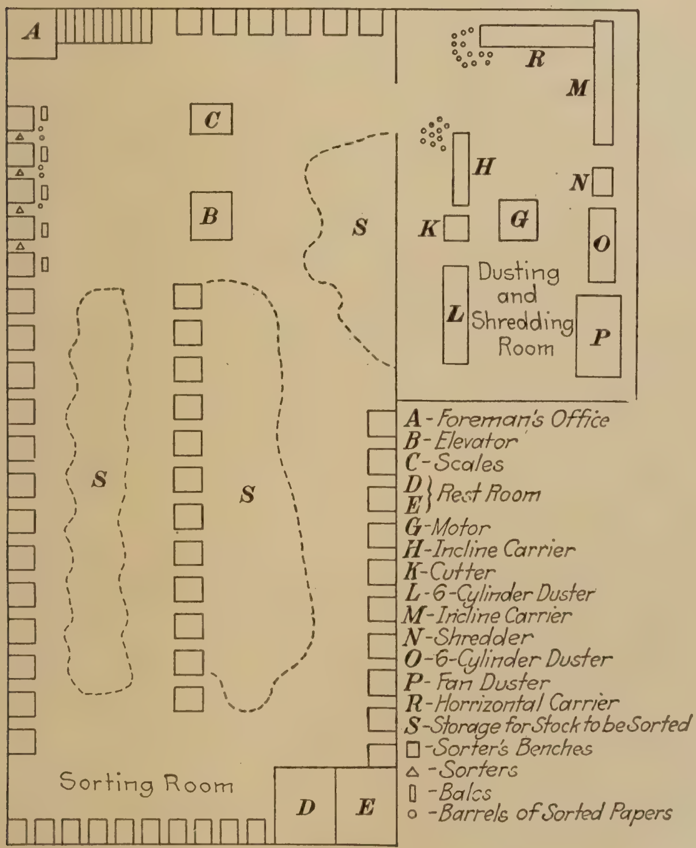


Fig. 3.

making it too costly to sort, he holds up the unloading until he is further advised by the purchasing agent or the sorting-room foreman. This decreases the expense of sorting and increases the efficiency of the sorters.

Fig. 3 represents a layout of the **bench system of sorting** old papers. The sorting benches are arranged along the sides of

practically the entire room; this allows plenty of space in the center for trucking the baled and sorted waste papers.

23. Testing Paper for Mechanical Pulp.—On receiving the bale of papers, the sorter first removes the tag, which she carefully retains; for it represents what the bale weighs, and her pay is based on this weight, a common rate being 15 cents per 100 pounds. Her trained eye tells her at once how any particular bale will sort. She can frequently pick out groundwood (mechanical) pulp sheets, which are termed **print,** by the general appearance of the paper; if the paper is old, the yellowish color indicates at once that it is print. As a further test, she occasionally sprinkles a solution of aniline sulphate over the papers as they lie on the bench, the strength of the solution being ½ pound of ordinary aniline sulphate to 5 gallons of water. If any of the papers turn yellow after being sprinkled, they are at once discarded as print. This test is widely known, and it is extensively used, when the price of aniline sulphate is normal. When using a solution of the strength mentioned, the test is rather slow; consequently, for a more rapid test, a solution composed of equal parts of nitric acid and water is used to identify print. As an indicator, this latter solution acts almost instantaneously, giving a dark brown color to print.

Phloroglucine is also a very satisfactory instantaneous indicator; it is made by dissolving 1 gram of phloroglucinol in 50 c.c. of ethyl (grain) alcohol and 25 c.c. of concentrated hydrochloric acid; the solution should be kept in an amber-colored bottle. This solution imparts instantaneously a deep red coloration to groundwood. Another rapid test, which has quite an extensive use, is prepared by making a strong solution of caustic soda or soda ash; this also gives a yellow or brown coloration to print.

24. The nitric acid test is not always certain, since it will give a brown color reaction to sulphite also. Hence, when aniline sulphate is not to be obtained, and if the nitric acid test is not positive, the sorter must refer to the foreman (or to his assistant, the floorman), whose long experience enables him to judge the paper in question by looking at it or through it, tearing it, or by trying the acid test himself. If there is any doubt at all in his mind, the paper is discarded; for, as previously mentioned, groundwood, or mechanical, pulp will cause trouble later in making a clean sheet of paper.

25. Rate at Which Sorting Is Performed.—When a bale has been opened and the sorting begun, if it appear that close sorting will be required in order to remove all the print and discards, the sorter is required to work by the day. She is thus enabled to earn a fair wage, perhaps $2.65 per day. Otherwise, she would hardly be able to sort more than about 700 to 800 pounds per day, for which she would receive not to exceed $1.25.

The quantity sorted per day, and the consequent cost of sorting, depends directly upon the quality and grade of the papers as received. The grades of waste papers chiefly used in book-paper mills are the following: magazine, book, over-issues, unstitched, lithograph, ledger writing, solid ledger and perhaps some shavings.

Solid magazines are easily sorted. After removing the print magazines, the names of which are well known to the experienced sorter, the deep-color covers of the selected magazines are torn off and placed in a container that receives this kind of discards. Solid school book is also easily sorted, requiring only that the book backs be torn off and the book divided into two or three parts. Over-issues do not require sorting, for they run uniform, and they are fed direct to the duster by the conveyor; this is also the case with lithograph and unstitched papers, provided they are not received in sheets too large for the dusters to handle. Solid ledgers require only that the binding be torn off and the paper separated into suitable thicknesses, about $\frac{1}{2}$ to $\frac{3}{4}$ of an inch. No. 1 hard and soft shavings seldom require sorting. On the above grades, each sorter can handle 2800 to 4000 pounds in 10 hours, depending on her dexterity and speed, and the cost of sorting is at a minimum, or 15 cents per 100 pounds.

However, mills are seldom so fortunate as to receive such fine packings; such lots come only occasionally. The usual run is No. 2 book, magazine and mixed ledger. Although these lots are supposed to have been graded by the packers with due care, all sorts of papers may be found in them. The papers must all be handled separately; and the amount sorted will vary from 1300 to 2500 pounds, averaging, usually, about 2000 pounds per sorter per day of 10 hours.

The mixed-ledger grade causes the greatest difficulty; it is nearly always sorted by the day, and at a rate of about $2.65 per day. In order that a sufficient supply may be on hand when necessity demands an immediate cooking of 30,000 to 40,000 lb.,

5 or 6 sorters are constantly employed on this grade of stock. It is obvious that this amount could never be sorted at short notice at a normal cost.

26. Loss in Sorting.—The sorters' discards constitute the first shrinkage or loss. All discards are classified as follows: Print, colors, bagging, carpets, wrappers, tobacco paper, wire and rope. For the period of a year, the amounts and percentages of these discards are shown in the following table:

	Total paper sorted (lb.)	Total discards (lb.)	Total discards (per cent)	Discards consist of the following:			
				Print	Colors	Backs	Bagging, etc.
Yearly total....	13,273,076	881,423	6.64	4.11%	1.45%	0.25 %	0.83 %
Daily average..	45690	3034	6.64	1874 lb.	665 lb.	114 lb.	381 lb.
Monthly average..........	1,106,089	73,452	6.64	45,367 lb.	16,090 lb.	2772 lb.	9222 lb.

From the above table, which was compiled from daily records, the per cent of total discards is 6.64%; this is the first direct shrinkage in handling old-paper stock, as it is supplied to the general trade. The table also shows that 4.11% of the discards, or 60% of this shrinkage, is due to print or groundwood. By the use of better graded or better selected stock, such as over-issue magazines of standard quality, this part of the shrinkage can be reduced greatly.

27. Containers for Sorted Papers.—After being carefully sorted, the waste papers are placed in barrels or other suitable containers, which will hold 100 to 150 pounds each. The containers are placed alongside the benches of the sorters, and, when filled, are trucked away to the conveyor. The work of trucking, which is performed by men, appears to be quite laborious, inefficient, and an antiquated system; but it possesses some good features, however. For instance, each container is numbered with the sorter's bench number; and when the papers are thrown upon the conveyor that carries them to the duster, the two men who attend to this work carefully examine the papers for any discards that may be present. If the amount thus picked out runs high, the container is returned to the sorter, with the papers that still remain in it, with instructions to sort it over again.

CARRIER SYSTEM OF SORTING

28. Description of Carrier System.—By **carrier system of sorting** is meant the process of handling old-paper stock from the bale direct to the carrier or conveyor; this system is illustrated in Fig. 4. Here the outline *a b c d e f* represents the same rooms as shown in Fig. 3, but with such changes in their arrangement as will adapt them to the carrier, or conveyor, system of sorting paper stock. Note the simplicity of the new arrangement, and gain in floor space, for paper storage.

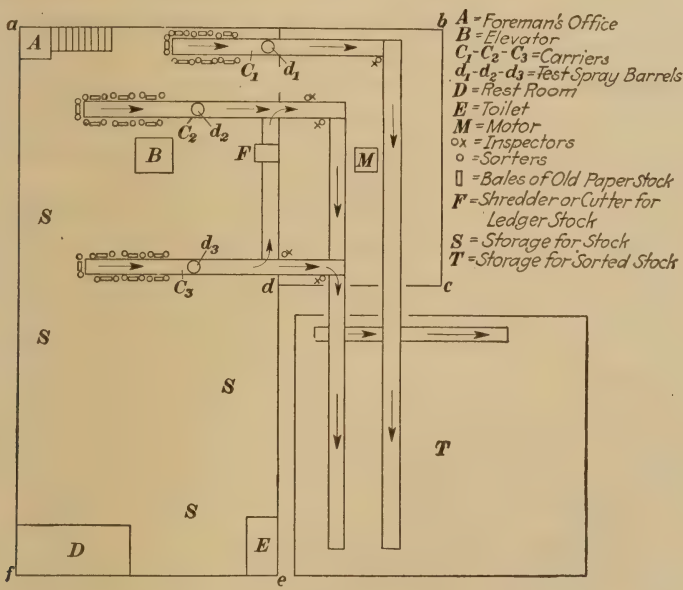


FIG. 4.

The bales of paper stock are arranged on both sides of the carrier C_1, C_2, C_3, which may be made of any suitable length; one having a total length of about 55 feet, and a width of $2\frac{1}{2}$ feet, has been found to be convenient and efficient. Three (3) bales of stock are placed on either side of the conveyor, and one bale at the head (or starting point) of the continuous belt. Two girls (sorters) are stationed at each bale, as shown diagrammatically in Fig. 4; thus 14 girls sort 7 bales directly onto the conveyor. The discards may be put into baskets or boxes, or they may be thrown into a chute under the carrier. At the mid point of the belts, sprayers d_1, d_2, d_3, are placed; these furnish a con-

tinuous fine spray of a solution of aniline sulphate or other indicator (see Art. **23**) directly upon the surface of the papers, as they pass by on the conveyor. An elevated barrel of solution, connected to a perforated pipe over the conveyor is a good arrangement.

The speed of the conveyor is 55 feet per minute; and when the belt has traveled 20 feet (which takes 22 seconds), the indicator solution will show the presence of groundwood, if any be present in the sorted papers. The use of this spraying test is very necessary, by reason of the prevalence of bleached groundwood in book papers. Since it is impossible to identify bleached groundwood by eye, it is necessary to test every sheet of paper on the carrier. All groundwood book paper is sent to the mill that uses paper of this kind. Two women inspectors are stationed at the delivery end of each carrier; their duty is to throw out any sheet that shows the typical color reaction of the indicator.

It is obvious that the sorters who are grouped around the receiving end of the carrier cannot use up too much time in close sorting; they must keep the surface of the carrier completely covered with papers at all times. They must, therefore, be able to sort by sight, and they must have a good knowledge of the general run of paper stock. Anything that is groundwood, or which appears to be groundwood, or concerning the nature of which there is any doubt in their minds, is at once thrown out as a discard. The discards thus thrown out from the carriers are then closely sorted and tested at the usual sorting benches.

29. Advantages of the Carrier System.—It has been stated that, with the carrier system, 20 girls can turn out 50,000 to 55,000 pounds, gross weight, of paper stock per day of 8 or 9 hours. Taking the lower figure and assuming that each girl receives \$2.65 per day, the cost per 100 pounds is $\frac{\$2.65 \times 20}{500} = \$0.106$ = 10.6 cents. This may be compared with 46,000 pounds, gross weight, of paper stock, sorted by 30 girls by the bench system, at a cost of about 15 cents per 100 pounds.

Further advantages of the carrier system are: the decreased wear and tear on the floors; increased storage space, by eliminating the sorting benches; and the elimination of one-man trucking barrels and containers, which are required with the bench system.

DUSTING THE PAPERS

MACHINERY IN DUSTING ROOM

30. Machines Used.—The machinery in the usual dusting room consists of the conveyors, railroad duster, fan duster, and the dust-collecting apparatus. For a capacity of 20 tons in 10 hours, all the necessary power is supplied by a 35-h.p. motor. Drives for each of the above mentioned separate units are taken from a line shaft.

31. The Railroad Duster.—The old method of handling papers consists in emptying the containers, full of papers, onto a conveyor that runs at a moderate speed. Here the papers receive a searching scrutiny for discards, and are then carried on a second conveyor belt, which moves at about twice the speed of the first belt. The second belt carries the papers to the railroad duster, in which the papers are threshed, shredded, and thoroughly separated into individual sheets. The shredding is accomplished by feeding the papers between two rolls having staggered pin teeth. The general details of a railroad duster are shown in Fig. 4, in the Section on *Preparation of Rag and Other Fibers*. A duster of this type, 4 feet in width and having 6 cylinders, has a capacity of 5000 pounds of waste paper per hour.

32. The Fan Duster.—The end of the railroad duster empties into the fan, or cylinder, duster. One type of fan, or cylinder, duster is shown in Fig. 5, Section on *Preparation of Rag and Other Fibers*, in which is a central shaft, with wings, revolving rapidly, and an enclosing screen cylinder, which revolves slowly.

The general action of a fan duster is similar to that of other rotary dusters in use. The papers, which are introduced into the feed aperture of the slowly rotating screen, are rapidly struck, tumbled, and loosened up repeatedly by the fast-revolving beater; this action separates the dust and dirt from the papers, which then fall down through the screen to the bottom of the casing. This occurs while the papers are progressively beaten and tumbled along through the screen, to be discharged in a loose condition.

33. Dusters for waste papers are often made similar to the one just described, but without the central shaft and its wings. In such machines, the papers are moved forward by making the

screen in the shape of a frustum of a right cone. The papers are fed in at the small end and discharged at the other end, usually upon a belt conveyor or into a chute.

34. To render the fan duster with a cylindrical screen capable of operating progressively and to tear the papers apart, beat, dust, and freely discharge them in a loose condition as fast as they are properly fed into the rotary screen, the screen is preferably provided internally with a series of projecting bars. The bars taper, and those at the receiving end are much larger than those at the discharging end; this gives virtually a conical shape internally to the screen. The rotating beater also has pin teeth, and its general outline corresponds to that of the screen, though its diameter is smaller. In operation, the beater may make 30 revolutions to 1 revolution of the screen; this ratio of 30:1 is not fixed, and it may be considerably greater or less. When the screen is about 10 ft. long and 5 ft. in diameter at the large end, and the beater is of corresponding size, a good speed for the screen is 8 to 10 r.p.m. and for the beater 250 to 300 r.p.m. However, good work may be done even though they revolve much faster or slower. The fan duster discharges the dusted papers onto a conveyor belt, and this, in turn, delivers them to the cooking tanks or to storage bins.

35. Power Required.—The power necessary to drive the conveyor belts is estimated to be 1 to 2 h.p.; for the railroad duster, 10 h.p.; for the fan duster, 5 h.p.; and for the exhaust dust fan, about 10 h.p. These figures vary, of course, according to the load on the machines.

36. The Dust.—The exhaust fan is connected to both dusters; it carries off a continuous stream of air that is laden with dust and dirt of all kinds, which is conveyed to a dust collector, where the dirt is removed and the air is purified before being discharged outside. The amount of dust removed varies, of course, with the kind of stock being handled; in any event, it is considered to be an inconsequential item, say 100 to 150 lb. per day in a plant having a capacity of 40,000 lb. of paper.

A sample of the dust was tested. After being ignited, the ash was white in color and was proved to consist of clay or insoluble silicate. As would naturally be expected, volatile organic matter constitutes the greatest part of the dust, which really consists of pure pulp fibers, in the main, and would serve

as an excellent filler in certain papers. An analysis of the dust showed it to contain the following:

	Per Cent
Moisture at 105°C	5.90
Pulp fibers	77.41
Clay	13.13
Alum	2.30
Calcium sulphate	1.25
Total	99.99

PAPER SHREDDERS

37. Methods of Handling Papers for Shredding.—Some mills change the method of handling the sorted papers from that usually followed. In one instance, in its endeavor to have the paper shredded better, the mill discards the use of the railroad duster, and employs a shredder, which reduces the paper to irregular pieces, about 4 to 8 inches square. The shredder has an exhaust fan connected with it, and delivers the papers to a continuous conveyor rake. The rake drags the papers up a short, inclined, coarse-meshed screen, in which much of the finer and heavier dirt is sifted out. The papers then go from the screen to the fan duster, where they are treated as previously mentioned.

TYPES OF SHREDDERS AND CUTTERS

38. A Popular Shredder.—There are a number of good paper shredders on the market, and in use in various mills, which reduce the paper to a size that will quickly absorb cooking solutions. A short description of several of these machines will afford information concerning the principles made use of in their operation.

Fig. 5 shows two views of a popular make of shredder. The rolls Q open up the papers and pass them to the shredding rolls R, which are cleared by pin roll P. The capacity of the machine is 12 tons of book stock in 10 hours. From 6 to 10 h.p. will drive the machine at capacity, and no mechanical skill is required for its operation.

39. An Efficient Type.—Another efficient type of paper shredder is shown in Fig. 6; it is running satisfactorily at

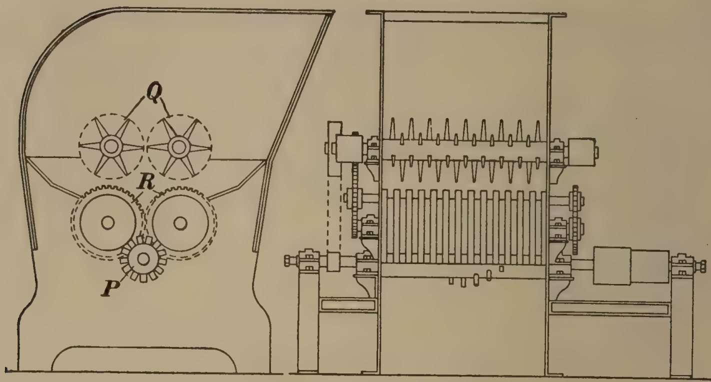


FIG. 5.

several plants in the United States and Canada. The machine is composed of two rolls R, having projecting pins P. One roll runs at a speed of 500 r.p.m. and the other at a slower speed. The flywheel F takes up much of the shock and promotes smooth

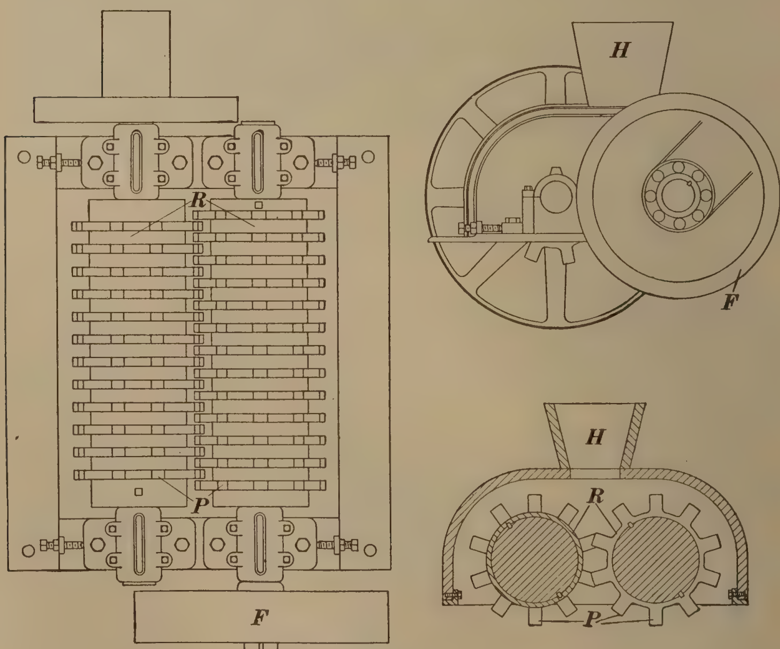


FIG. 6.

running. This shredder takes 6 to 8 h.p. to operate it, and its capacity is 4000 pounds of book stock per hour.

After coming through the shredder, the pieces will average about 2 inches square, and they are so well separated that the cooking solution can percolate through them to the best advantage. The machine is automatic in its action, and the only attention it needs is a conveyor to carry the paper to the hopper *H*, at the top of the machine, and to another conveyor that removes the pieces to the bins or cookers.

40. Stock Cutter.—A stock cutter is shown in Fig. 7; it is installed in many mills for cutting solid ledgers, books and heavy magazines. In operation, the waste paper is put into the wooden

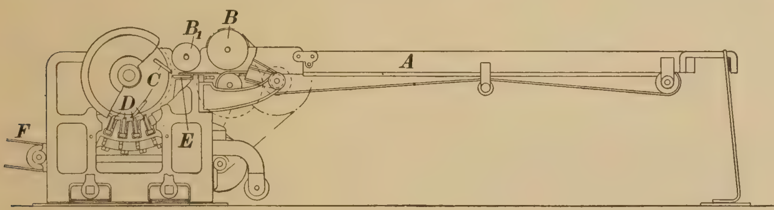


Fig. 7.

apron box *A*; it is then carried up by the rubber or canvas apron until it is caught by the large, or breaking-down, feed roll *B*; this roll carries the paper forward to the small feed roll B_1, which carries the paper forward until it is cut by four revolving knives *C*, two of which are shown in the illustration, which shear against the top bed knife *E*. The stock is then carried down, and is cut and re-cut by the four revolving knives against the four cradle knives *D*. The weight of the machine is 8300 pounds; it is so constructed that the shock and jar that result from the cutting of thick books is hardly noticeable, giving practically no vibration. Its rated capacity is a minimum of 2½ tons per hour; but it has cut and handled 5 to 6 tons per hour, depending on the amount of power that can be furnished to it, and the length of cut desired for papers. Belt *F* removes the cut papers.

41. A Well-known Shredder.—Another well-known shredder is shown in Fig. 8. Here *A* is a roll with projecting pins *P*, to open the stock, which is fed through the hopper *H*. The shredding is completed by blades or bars *B* on roll *R*, and the paper is delivered at *T*. This shredder takes from 5 to 15 h.p., depending on the size of the magazines or books fed to the shredding rolls.

Note the different speeds of the two rolls, which is indicated by the difference in size of the pulleys *F* and *G*. This machine will shred 3 to 4 tons of magazines per hour. No repairs or maintenance charges have been necessary in mills that have had this type of machine for as long as five years, and no labor is required for attendance.

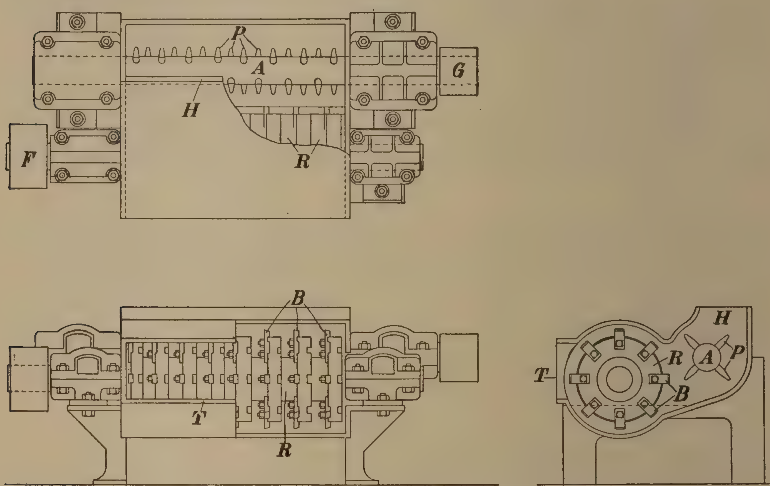


FIG. 8.

42. A Powerful Shredder.—The writer visited a mill that had recently installed a new type of paper shredder. The work being performed with this machine was quite remarkable. Large 35- to 40-pound books, from which the covers had been removed, were fed to the shredder and cut into almost a million pieces, not over 1 inch square. The shredded papers are expelled from the machine by a strong suction of air; they are then sent through a rotary-screen duster to a fan duster, which blows the papers to the cooking tanks.

This shredder, shown in Fig. 9, is a massive machine, weighing 8500 lb. The cylinder *A* is 30 inches long, and carries 20 knives *B* (only 4 are shown in the cut) that cut against 4 stationary knives *C*, located under the lower half of the cylinder and set in the frame. The cylinder is 36 inches in diameter, and makes 650 to 860 r.p.m. The length of the cutting edge of the revolving knives is 6 inches, and of the stationary knives about 38 inches. Consequently, when the paper stock is fed into the machine, it is

cut a number of times, and it is reduced to a uniform product that is easily handled with an air blower through an 18-inch pipe. The feeding spout *D* is a combination of inclined and vertical sides; *E* is a conveyor-belt roller.

The power required to operate the machine depends on the quantity of paper to be shredded. It is recommended that 50 h.p. be available when the production is 3 to 5 tons per hour, and that about 10 h.p. additional per ton of increased production per hour be available, up to the maximum capacity of the machine, which is 10 tons per hour. Hence, when operating at full capacity, $50 + (10 - 5)10 = 100$ h.p. should be available, though not necessarily used. On the date of the visit, the machine was producing 4 tons per hour; and it was computed from the ammeter readings that 35 h.p. was being used. Fig. 10 is a layout of the conveyors used to feed this machine properly.

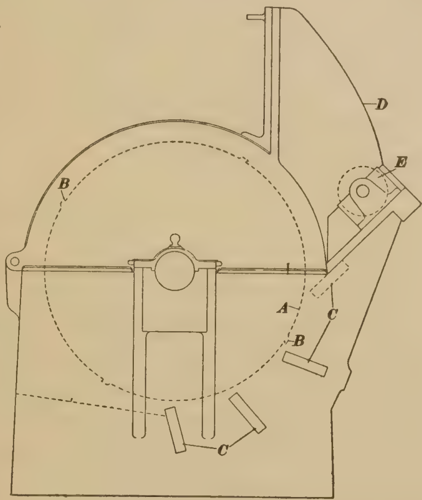


Fig. 9.

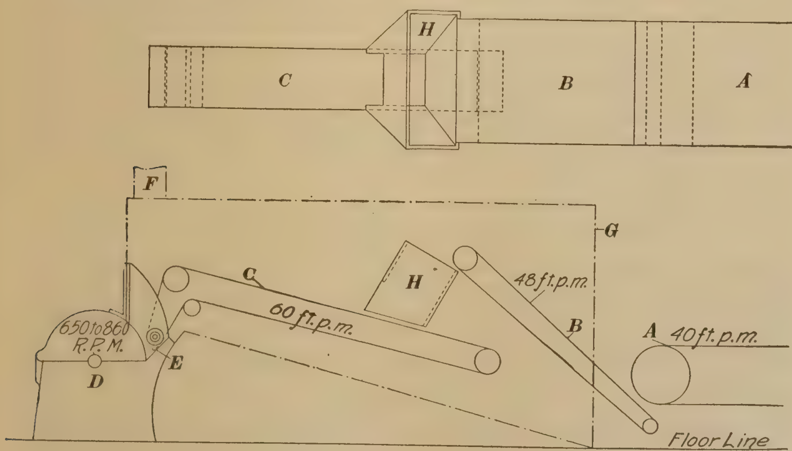


Fig. 10.

A belt conveyor *A* brings stock direct from the waste-paper sorting room and delivers it to a rubber-belt conveyor *B*, which delivers it to a hopper *H*, from whence it is conveyed to the shredder *D*. The papers are shredded and separated thoroughly, so that all impurities will be removed on passing through the fan duster. A leather scraper *E* keeps the paper from following the conveyor, and a pipe *F* carries the dust to the blower, which removes it from enclosure *G*.

HANDLING SHREDDED PAPERS

43. Dusting Old Papers after Shredding.—Strange to say, the subject of dusting the old papers receives but scant attention; it is usually regarded as a mechanical process of dumping old papers through the apparatus, and no further thought is given to it. In reality, dusting and screening loose dirt from old waste papers by the fan duster in the dusting room, bears the same relation to the resultant finished paper that removing bark and rotten wood from the pulp wood bears to the production of fine, clean pulp.

To produce paper free from dirt, it is necessary to remove the greatest amount of dust and dirt at the initial stage of the process. If the duster delivers thoroughly dusted papers, the subsequent steps will be greatly simplified. The cut and torn papers from the shredder should be given a thorough dusting, using a machine of the types described in Arts. **31** and **32**, or even a single wire-screen cylinder.

44. Prevention of Clogging.—The variation in the rate of feeding of old papers to the dusters is an important point to be considered. The apparatus is built for a certain capacity, say 2500 to 4000 pounds per hour. Below the minimum and up to the rated capacity, the papers are delivered from the duster in good condition; that is, thoroughly disintegrated and dusted. But it sometimes happens that 4000 to 6000 pounds per hour are forced through the machine, causing it to become clogged, when it is liable to become dangerously overheated, by reason of the increased friction. The dust cannot then be properly handled by the exhaust fan, and it fills the air, making it almost impossible to live in such an atmosphere. As a consequence, the papers

will come out still dusty and dirty, through this overburdening process. To correct this, the dusting capacity should be increased, and the screening area of the rotary screen should be enlarged, to produce thoroughly dusted papers.

PURCHASING PAPER STOCK

COST CONSIDERATIONS

45. Reducing Cost of Sorting.—By using a few precautions, it is possible to reduce the first cost in the reclaiming of old papers. The first essential in reducing cost lies in the purchasing of old paper stock. Since the quality of the product of the mill is governed by its constituent materials, in other words, by what enters into the composition of the paper made, very careful and judicious selection of the waste-paper stocks is a prime requisite. Orders should be placed only with reliable packers, those that are known to live up to their guarantee of doing an honest business. It would be well to visit these packers at their sorting and packing rooms, noting the care they give to the handling of the papers as received, their equipment, and the amount of business that they conduct. Packers should receive specifications covering a strictly uniform, clean grade of papers, and they should follow out these orders to the letter. The Salvation Army has gone into the waste-paper business quite extensively, and their packings enjoy the reputation of being carefully graded and free from groundwood. They command a higher price for their wastes; but it is cheaper in the end to use their stock, or to buy of similar conscientious packers.

In purchasing paper stock, the only consideration of the purchasing department should be to buy only that stock which can be recovered to meet the standard grade of the mill and which can be delivered to the paper-machine beaters at the least cost per ton, as received. The method of getting the information for purchasing on this basis, as practiced in a Wisconsin mill, is to have the laboratory or testing department make a time, quality and shrinkage test on a unit lot of the paper offered on the market. These tests are then turned over to the accounting department, which estimates the cost per finished ton for the

various grades. An example showing records of these tests is given below.

Name	Gross weight of bales (pounds)	Weight and kind of baling (pounds)	Weight of dust (pounds)	Weight of bags and unfit paper sorted out (exclusive of baling) (pounds)	Weight of paper put in stock tank (pounds)	Weight of 60 % caustic soda put in tank (pounds)	Weight of 60 % caustic soda recovered (pounds)	Weight of 60 % caustic used (pounds)	Time of cooking (hours)	Time of washing (hours)	Time of bleaching (hours)	Weight of 35 % bleach used (pounds)	Weight of air-dry stock recovered (pounds)
A	8780	57, bags 382, paper 9, wire	$19\frac{1}{2}$	14, string 307, G-W paper	7991	277	102	175	$9\frac{3}{4}$	$2\frac{1}{2}$	$\frac{1}{2}$	113	5087
B	9031	230, bags 6, wire	20	5, string 859, G-W paper	7911	268	61	207	$10\frac{1}{2}$	$2\frac{1}{2}$	$\frac{1}{2}$	113	5217
C	9707	31, bags	20	269, G-W paper	9386	311	31	280	$10\frac{1}{2}$	3	$\frac{1}{2}$	113	6353
D	8666	122, bags 27, wire	19	298, G-W paper	8200	293	37	256	$10\frac{1}{2}$	$3\frac{1}{2}$	$\frac{3}{4}$	113	3707

Summary of Above Tests

(All figures based on weight of paper as shipped)

Name	Shrinkage in sorting room (%)	Shrinkage in rest of process (%)	Total shrinkage (%)	Girl-hours per ton for sorting
A	8.85	32.24	42.09	30.9
B	12.40	29.83	42.23	22.2
C	3.31	31.25	34.56	10.8
D	5.38	51.85	57.23	15.7

46. Choice of Stock.—Only solid magazines, over-issues, unstitched, school books and solid ledgers, together with lithograph and shavings should be used, to reduce the cost of sorting. These grades require the separating of the heavy colors only, and a sorter can easily handle 3500 to 5000 pounds per day. The shavings can be added directly to the beater, provided they are unprinted, and there is sufficient beater capacity for completely brushing out the fibers; sometimes shavings are first put through a pulper. Instead of trucking the papers after sorting, they can be sorted directly onto and delivered to the dusters by conveyors.

In place of tearing magazines and books by hand, the work is accomplished better and more quickly by using machinery.

IMPROVING QUALITY AND USING DISCARDS

47. Improving Quality.—The exclusive use of the grades mentioned in Art. **46** would increase the quality of the product, which would be more uniform in color and in cleanliness. The composition of the stock being constant, the subsequent cooking, washing, and bleaching operations would not be so variable. Paper free from groundwood specks and undissolved ink would be obtained, and an increase in price of from 50 to 75 cents per hundred pounds could reasonably be demanded. Further, because of their freedom from dirt particles, samples could be duplicated, a procedure not otherwise practicable. Finally, by employing the cutter for tearing and shredding these grades of papers, the labor now engaged in this work could be decreased 40% to 50%, without decreasing the output of the sorting room.

48. Utilization of Discards from Sorting.—The discards, which may average 40 to 50 tons per month, are properly sorted into classes; this is done in the sorting room, and necessitates no additional help. The print is usually separated into what is called *white print* and *colored print*. White print is sold as such to mills making cheap blanks and liners; colored print and heavy colors are usually sold for making into boards, and this is also the case with book backs. Occasionally, all these discards are worked over at the mill in which they originate, with about 10% of unbleached sulphite, which serves for making a fairly good quality of heavy card wrapping for shipping rolls, etc. However, considering the amount of dirt that must necessarily enter into this grade, and which pollutes the entire mill with refuse, it is not a paying procedure, since a much better grade of sulphite fiber wrappers may be made at almost the same cost.

The colors might be sorted to each color—such as blues, reds, greens, browns, yellows—and cooked separately, washed and partly bleached, and then worked over into colors again. Since a majority of the fibers of these colored papers is made up of soda and sulphite, a sheet could thus be made that would sell for a good price. The only drawback might be that only a limited amount of stock of each color could be obtained, with the consequent problem of disposing of small lots. Since deduc-

tions are made for excess discards when paying the original invoice of the paper stock, it is safe to say that it is more profitable to sell the discards outright, and there is no attendant loss in doing this.

QUESTIONS

(1) Explain the differences in the layouts for bench sorting and for carrier, or conveyor, sorting.

(2) What chemicals are used to detect the presence of mechanical pulp in waste papers?

(3) About how much dust is obtained from the dusting of waste papers?

(4) Why is it unwise to overload the dusters that handle the cut and shredded stock?

(5) How can the purchasing department help the superintendent to get better results from the treatment of waste papers?

COOKING, DE-INKING AND DE-FIBERING

COOKING PROCESSES

OPEN-TANK PROCESS

49. Methods of Cooking.—The methods for cooking and de-inking old waste papers that are now in use are few in number, insofar as the principles utilized are concerned. However, each mill usually employs certain variations, which it considers necessary for the successful treatment of waste-paper stock. The three oldest methods in use are: (*a*) Cooking in open- or closed-top stationary tanks; (*b*) cooking in cylindrical or globe rotary boilers; (*c*) cooking in horizontal-circulating cooking engines. These processes will now be discussed.

50. Cooking in Open Tanks.—This is by far the most usual method of cooking old waste papers; it is used extensively in a number of the older mills. It is designated the **open-tank process** because the cooking tank is not covered while the papers are being cooked. Most mills that use this process have their own ideas regarding the details, such as the strength of cooking liquor, time of cooking, kind of alkali to use, and temperature of the cooking liquor, and these differ very materially from the details of the original Ryan process (see Art. 8). These differ-

ences are the result of many years of experience; and the mills have, by degrees, reached the point where they now have sound data for properly cooking old paper stock.

51. The Cooking Tank.—The **cooking tank,** or **bleach tub,** as it is usually termed, is a stationary cylindrical tank *B*, Fig. 11, built of $\frac{3}{16}$-inch boiler plate; it is 10 feet deep, 10 feet in diameter at the bottom, and 10 feet 1 inch in diameter at the top. The plates are riveted so that all projections will be on the outside, in order to make the inside as smooth as possible. The tank is provided with a solid bottom *C* and a false bottom *D*. The false bottom is made of $\frac{3}{16}$-inch boiler plate, and in 8 sections, 4 of which, D_1, D_2, D_3, D_4, are shown in the illustration. To enable the cooking liquor to filter through to the real bottom, these sections are perforated with $\frac{1}{2}$-inch holes, spaced 3 inches apart from one another. This false bottom rests on a cast-iron spider, which has 8 arms F_1, F_2, etc. The spider rests on an octagonal framework of wooden blocks G_1, G_2, etc., 6 inches square in cross section. The space between the two bottoms serves to contain a large volume of liquor, which is forced up the 8-inch central pipe *H* by a steam injector *K*, when the cooking is in process. The arms of the spider are riveted, or otherwise fastened, by a flange *L* to the central pipe *H*. The top of the central pipe, which is about 9 feet long, is equipped with a baffle plate *P*, 10 inches in

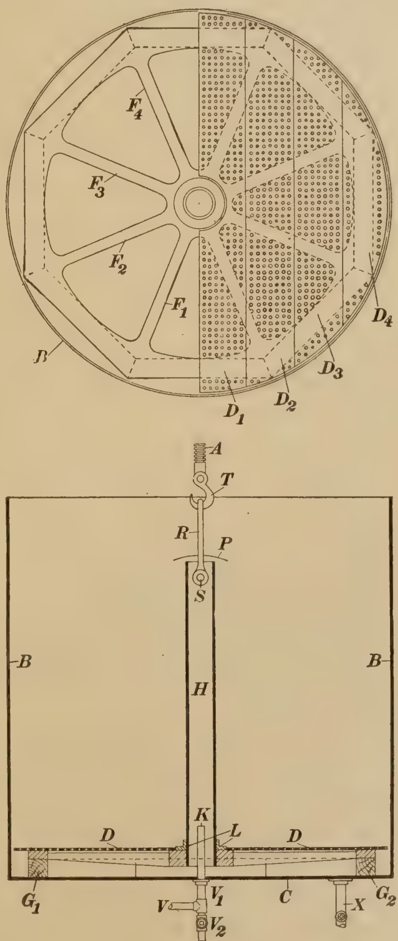


FIG. 11.

diameter, the under side of which is slightly concaved. The baffle plate is so designed that the liquor striking it is sprayed outwards and downwards, thus covering the entire exposed surface of the stock in the tank with a shower of liquor. Near the top of the pipe is a U-shaped hook or bale *R*, of $1\frac{1}{4}$-inch round steel, fastened by bolt *S*, for attaching hook *T* of the hoisting mechanism; hook *R* is allowed to swing downwards when not in use. *V* is a $1\frac{1}{4}$-inch steam inlet, V_1 is a $1\frac{1}{2}$-inch pipe, V_2 is a $1\frac{1}{2}$-inch plug valve for drain, and *X* is a 4-inch washout valve.

The lifting mechanism is supported conveniently by erecting a pier or column on either side of the tank. A spur shaft carries two sets of pulleys, one for raising the spider slowly and the other for lowering it rapidly. The pulleys are belted to a main shaft that is situated at a convenient distance from the spur shaft. One open and one crossed belt are used. The spur shaft carries a bevel pinion that meshes with a large bevel gear, which turns like a nut on the long screw *A*, and lifts or lowers the spider. Over each tank is placed a hood, which has a vent for carrying off the steam and fumes.

52. Furnishing the Papers.—After being thoroughly dusted, the papers are discharged onto a conveyor belt, which carries them to another belt on the floor above the cooking room; this latter belt brings the papers to chutes, which may be arranged to deliver the papers directly into the tanks; or the papers may be charged in armfuls at a time, by two men. This latter method may at first appear to involve extra labor and time; nevertheless, it is the better method, because of the more uniform distribution of stock.

53. Furnishing and Heating the Liquor.—Before beginning to furnish (charge) the papers, the liquor is made up to strength, and the correct volume of liquor is added to the cooking tanks. It is then heated, by injecting steam under the false bottom, to about 200°–210°F. At this temperature, the liquor is forced up the central pipe and against the baffle plate, and is sprayed outwards and downwards, in a full circle, over the entire upper surface of the stock. The spraying process is intermittent; it occurs only when the pressure of the steam under the column of liquor in the central pipe overcomes the weight of the volume of this liquor in the pipe, and projects it upwards against the baffle plate; and it continues until the *excess* pressure falls and

becomes zero. The liquor then filters through the papers or runs down the sides of the pipe or the tank, returns to the bottom, and forms a new and cooler (also heavier) volume of liquor for the steam pressure to work against.

54. Dry Cooks.—The spraying action should be so regulated as to occur about 4 to 6 times a minute during the period that the papers are being cooked. Evidently, this spraying must occur more frequently while the papers are being furnished to the tanks, and it is then increased to about 10 to 15 times per minute. For this reason, some mills decidedly oppose continuous furnishing of papers direct from the chutes. They claim that papers falling continuously are not evenly distributed around the tank, that they are liable to become bunched or packed, forming pockets of dry papers that do not come into contact with the spraying liquor. This results in what is termed a **dry cook** or *bad bleach;* the ink is not acted upon, the sizing of the papers and the oily vehicles of the ink are not thoroughly saponified, and on the later washing of the papers, it is impossible to wash off all the ink and secure a clean, white pulp.

In addition to the presence of the ink particles, another bad feature of a dry cook is that the paper itself, by not coming in contact with the liquor, will not be entirely reduced to a pulpy mass in washing, and it will not be thoroughly brushed out during the short treatment it receives in the beaters. Still, a considerable percentage is fine enough to pass lengthwise through the machine screens; and, on being made into paper and calendered, these dry particles cause a mottled or blocky appearance in the finished paper. These troubles are attributed to the method of scattering the papers across the top of the tank. The remedy is to furnish the papers, particularly hard-sized ledger and lithograph, in scattering armfuls; the papers are thus evenly distributed, and they all become saturated with the spraying liquor before the next armful is thrown in the same place. With soft-sized magazine and book stock, the papers may be delivered from the chutes directly into the tanks; they are then raked and distributed evenly over the path of the spraying liquor by two men, one on either side of the tank.

55. Preparation of Cooking Liquor.—In preparing a new cooking liquor, or fresh bleach, 1200 pounds of soda ash are dissolved in

water, heated, and agitated until thoroughly dissolved; sometimes the equivalent in caustic soda is used instead of soda ash. This operation is carried on in the alkali room, on the floor directly above the cooking, or bleacher, room. The liquor is run from the dissolving tank into the cooking tank, which has previously been cleaned out and made ready for the new alkali liquor. Fresh water is turned into the cooking tank until it reaches a depth of $4\frac{1}{2}$ feet; with a tank 10 feet in diameter, this is equivalent to a volume of 2644 gallons, or a strength of liquor containing $1200 \div 26.44 = 45.4$ pounds of soda ash to 100 gallons of cooking liquor. With a hydrometer, this liquor should test 9.15°Tw. or 6.34°Be., at 60°F.; at 180°F., which is the temperature at which the mill test is usually made, the reading should be 3.15°Tw. or 2.24°Be.

This strength of liquor will thoroughly cook 6000 lb. of ordinary soft-sized book and magazine paper. After long years of practice, this amount of alkali has been observed to produce the best results, and it is taken as the standard for this grade of stock. For cooking hard-sized ledger and deep-colored, hard-sized lithograph papers, the strength of liquor customarily used is 6.9°Be. or 10°Tw. at 180°F.; this reduced to 60°F. gives a reading of 10.7°Be. or 16°Tw. This reading is equivalent to 7.57% of soda ash by weight, or 1750 pounds of soda ash is required to be used to give this test.

While this amount of alkali is excessive, it is not considered economical to reduce it; because the cooked papers might then show defects of one kind or another, and these would at once be attributed to the way the paper was furnished and to the wrong strength of liquor used.

56. Before allowing the papers to be cooked over night, the liquor is again tested. A sample is taken while the liquor is being sprayed over the papers, and hydrometer and thermometer readings are also taken. By referring to the scale of corrections for the temperature, it is an easy matter for the alkali man to ascertain whether or not the liquor is up to the required strength; if not, he at once adds more of the alkali solution. All the liquors are tested, and the results are recorded on the daily report sheets, together with the amount of alkali used for each cooking.

57. Duration of Cook.—The operation of filling each tank usually takes $1\frac{1}{2}$ to 2 hours to furnish 6000 pounds of paper. This is

allowed to cook from 5 to 10 hours, even 15 hours, at times. Light book and magazine can be thoroughly cooked in 7 hours, which is the minimum length of time in which it is possible to obtain good results. When there is a shortage of paper stock, a tank is hurriedly furnished and is cooked for 5 hours, but the results are far from satisfactory. Although most of the ink will have been acted upon, a small percentage will sometimes remain uncooked, and this will reduce the quality of the resultant sheet.

For most of the hard-sized ledgers and colored lithograph papers, 10 to 12 hours is considered sufficient, though if time is available, that is, if there is a large quantity of cooked papers ahead of the washers, the cooking time is increased considerably, even to 15 hours. This length of time is possible, if the papers are furnished in the first tank filled in the morning; the tank will be filled by 9 a.m., and the papers are ready to be taken off by midnight.

58. Steam Used in Cooking.—The amount of steam used in the cooking of the papers is an important factor in estimating the cost of the process; but no definite data have been obtained as yet regarding the amount consumed. The pressure on the main steam line is reduced by a valve to 30 pounds, the steam flowing through a $1\frac{1}{2}$-inch pipe to each cooking tank. Here the pressure is again reduced by a valve, and the amount of steam used is regulated by the number of intermittent showers or sprayings of liquor that are desired per minute.

That the amount of steam used is excessive, is admitted by all those who have inspected the system. At times, after all the liquor has been sprayed up, it fails to return quickly enough to form a seal below the false bottom, for the steam to work against; the result is that live steam continues to be injected upwards into the open air until this seal is again formed. In a few mills, in order to retain the heat of the steam, the tanks are encased with wood or with an asbestos covering.

59. Reducing Steam Consumption.—To reduce the amount of steam used, it was suggested that the tank be covered with a wooden or iron cover while the cooking was in progress. An opening 1 foot square was made in the cover, about 1 foot from the edge, and to this was attached a wooden outlet, which conducted the steam and vapor outside the building. While this arrangement reduced very materially the amount of steam used, it

caused other troubles, due to excess condensation, etc., and it was discontinued.

One fact noted while using the cover on the tank, was the great difference in the amount of heat remaining in the papers, when they were ready to be taken off. The papers in the tank were so hot that it was necessary to allow the cook to stand and cool off, until the other cooks had been removed from their tanks. Even then, the papers were removed only with the greatest difficulty and discomfort.

Although the increase in the amount of heat retained by the papers adds to the difficulty of handling them after cooking, the heat hastens the saponification action; the ink is more completely broken up and dissolved, and it is more easily washed out in the washers; the tendency of the ink to collect into small lumps is overcome, because, after being subjected to the continued heat action, the particles of ink are very finely subdivided and will more readily form an emulsion with the cooking liquor. Also, since more than two-thirds of the hotter liquor is recovered, and much more drains away while the papers are in storage, the subsequent washing time for the papers is lessened considerably.

60. Removing the Cooked Papers.—After the papers have been allowed to cook the required length of time, the cooked papers are raised by a hoisting device that lifts the false bottom from the tanks. The hoisting mechanism is located on the floor above the cooking room. A 25 h.p. motor will furnish sufficient power to raise five cooks at the same time.

When the false bottom has been raised to within 6 inches of the top of the tank, it is stopped; the papers are allowed to cool, and the liquor drains back into the tank. Two men clad in the scantiest attire, consisting usually of overalls and wooden shoes, mount to the top of the papers and shovel them off with pitch-forks into large cars or containers, which are grouped around the sides of the tank. The work is laborious; it is also distasteful, because the steam that continually arises is filled with peculiar odors from the papers. It usually takes 2 hours to fork off 6000 pounds of the cooked papers, and the working time is limited to 5 hours for each man; the cost of handling the cooked papers is quite small.

61. Other Methods of Removing Papers.—A method of removing the cooked papers that has been tried and found to

be very satisfactory, is to attach 4 vertical rods, spaced equally distant apart around the false bottom; when the cook is raised, these rods form a kind of basket, and may be suitably fastened to an arrangement that will allow the entire mass of papers, still remaining on the false bottom, to be swung clear of the tank, onto a track system, and moved either by a crane or pulley over to a draining pit. The false bottom is so built in this case that it permits dumping by turning on hinges. After draining in the pit for some time, the papers may be fed into a hopper or kneader, located below the pit, which will so condition the papers that they can be pumped to the washers.

To accomplish this work with fewer men, one enterprising mill has laid a small, narrow-gauge, track system, sunk in a concrete foundation. The tracks extend from the tanks to each washer in the beater room, and to side tracks in the bleacher room; the latter serve to store papers ahead of the washer. By means of this track system, with small cars made to fit the rails, one or two men can easily convey the cooked papers to the washers. Some mills have an electric truck, which has an arm that is run under the box of stock, lifts it, and carries it anywhere, with no manual labor at all.

62. Recovery of Chemicals.—The recovery of the alkaline cooking liquor used in the open-tank process is, perhaps, the best point in favor of this method of cooking old paper stock. The fact that no additional care, expense, or trouble is incurred in effecting the recovery of the liquor is also an attractive feature. Moreover, the cooking of paper stock is not nearly so satisfactory when done with fresh liquor as it is when part recovered liquor and part fresh liquor are used, because the soap or saponified oil that is contained in the recovered liquor has a definite and essential function to perform in emulsifying the carbon black and removing it in washing.

The rate of ascent during the raising of the false bottom carrying the cooled papers, is very slow; it generally takes 30 min. to lift the papers 10 feet. This is a lifting speed of only 4 in. per min.; and it is so slow that nearly all the liquor not absorbed by the papers finds its way to the remaining liquor in the tank. By thus slowly draining and running off the liquor, a varying percentage of the liquor is saved. The degree of variation depends upon the nature of the papers, the soft, porous papers acting like a spongy mass to retain more liquor than the hard-sized,

stiff, rag-stock papers. Another cause for variation is the loss of liquor due to splashing over the side of the tank while spraying with too great pressure of steam; also, when raising the papers, the liquor continues to ooze out of sides, and drains down to the rim of the top of the tank. If there is no opening by which the liquor can return to the tank, it will run over the sides and be lost in the drain to the sewer. However, with all these losses, the average daily recovery is about 66⅔% of the liquor used. In some cases, the recovery has been as low as 24% and as high as 92%.

63. Losses in Recovery.—Figures tabulated from exact data, to show the variation in the percentage recovery of liquor that occurs from day to day under ordinary conditions, with seven tanks in use, indicated a maximum variation of 33.4% to 88.9% of recovered liquor. The monthly averages ran from 66.00% to 78.03%. Two tanks were furnished with new liquor during this period. The average recovery of soda-ash liquor on all tanks was 71.34%, with 146 cooks.

In this tabulation, the variation was quite evident. At first, it was thought that the highest recovery figure, 88.9%, did not represent the same value as the corresponding volume or per cent of new liquor. It was claimed that from 20% to 30% of the alkali content was consumed in the saponification of the ink, colors, and sizings, and that the condensation of the steam caused the increase in the volume of the liquor. It is true that there is some decrease in the strength of the alkali content of the liquor by saponification; there is likewise considerable condensation while the liquor is being raised to the boiling point, though after that, the steam acts only as a projecting force to spray the liquor. The volume of steam and vapor given off on spraying is about equal to the amount of steam injected into the tank.

As previously stated, there is a loss of liquor over the tanks in spraying, and in the liquor that oozes from the sides of the papers, while being raised, which fails to return to the tanks. There is a further loss in the liquor that drains away while the cars are standing in storage. All this liquor, which now goes to the sewer, could be very easily saved and recovered, and at slight cost. A concrete flooring, with grooved drains, would conduct all this liquor to a common catch-all tank. A catch pan could be riveted to the top of the cooking tank, into which would drain all the liquor that ordinarily goes to waste when the papers are raised.

64. Increasing Recovery by Washing.—The percentage of alkali recovered could be further increased by washing the papers once or twice with warm water, while they still remained in the cooking tank. This would necessitate draining off the liquor from the tanks before adding the wash water, in a manner similar to that of washing chemical pulp. But this is not desirable, since the soapy liquor sticking to the papers acts to remove the carbon black, when put into the washing engine. The strong liquor should be stored separately, and the wash water should be stored by itself in another tank; in this way, with a little care and attention, the strength of the liquors in all the tanks would be the same. The strength of the recovered liquor could be determined, and its volume readily ascertained. Then, by using the wash water to dissolve the correct amount of soda ash, and adding to the strong liquor, the strength and volume of the mixture could be brought up to the standard strength for cooking.

ROTARY-BOILER PROCESS

65. Reasons for Using the Rotary-Boiler Process.—The cooking of old-paper stock in rotary-cylindrical and rotary-globe boilers is a later development that is viewed with great favor by all the newer mills. The cleanliness of the cooking room, the absence of steam and condensation, and the ease with which the cooked papers are handled, are the great assets of this method. The claim is also made that it is a much more economical process.

Although the saving in labor, both in filling the rotaries and in the subsequent washing operations, represents a very good return on the investment, the chief argument in favor of the rotary system is the uniformity of the cooked product.

The general arrangement of a cylindrical rotary boiler installation is shown in Fig. 12. Details of the boiler are given in the Section on *Preparation of Rag and Other Fibers.*

66. Discussion of the Process.—The preliminary sorting and dusting is much the same as in the open-tank process. A few mills have, very wisely, added cutters or shredders to their equipment, which help to condition the papers for the best results in cooking. The tendency for the papers to roll up into thick wads, caused by the slow, revolving motion of the boiler, sometimes gives trouble. These thick wads of paper are not

thoroughly saturated with steam and cooking liquor, and the result is the same dry cook mentioned in Art. **54.** To avoid this, the papers are first cut into short strips or are shredded into irregularly shaped pieces, that they may come more readily into contact with the liquor, and not roll up into wads.

However, improvement in the design of the rotary-cylindrical boiler in the last few years, has overcome the tendency of the stock to roll up, or ball up, into dry wads. Investigation has shown and practice has proved that, by increasing the number of the internally projecting pins and by staggering and placing them in proper positions, the rotary will not only cook thoroughly but it will also act as a de-fibering machine. In the 8 × 24-foot rotary, the present practice calls for a varying number of these rag or de-fibering pins, which are usually arranged in 5 to 9 rings of 8 pins each, the 8 pins being spaced uniformly about the circumference. The pins are made of $\frac{1}{2} \times 1\frac{1}{2}$-inch iron, bent to the shape of a U, and 9 in. high; they are riveted to the shell. The specifications formerly in use designated only about 9 or 10 of these pins. One mill that is equipped with this new type of rotary reports that it has abandoned entirely the use of cutters and shredders, and that it has even eliminated the railroad duster and the fan duster in its sorting and dusting rooms. Instead of using a 50- to 60-h.p. motor to drive the sorting-room equipment, as formerly, a small 5- to 10-h.p. motor now handles the load of the three or four sorting carriers, the papers are conveyed in their original condition directly to the rotaries, and a heavier cook can be handled. The charge has been increased from 7500–9000 pounds to 12,000–14,000 pounds.

Without a doubt, the older rotaries could not have accomplished what those of the newer type have done. It is a question, however, whether good judgment was exercised in discarding the dusting equipment at the mill above referred to. Dirt must be taken out some time; and the proper place is where the papers are dry and are in their original condition. Bearing in mind that the purpose of this mill was to keep the paper stock as flat and as compact as possible, the use of a revolving, tapering, cylindrical-screen duster would remove the surface dust by a tumbling action, and it would add but little, if anything, to the bulk of the paper stock entering the rotary boiler.

67. Fig. 12 shows the relative positions of the rotary and the dumping pit. Here R represents a typical 8 × 24-foot rotary; T

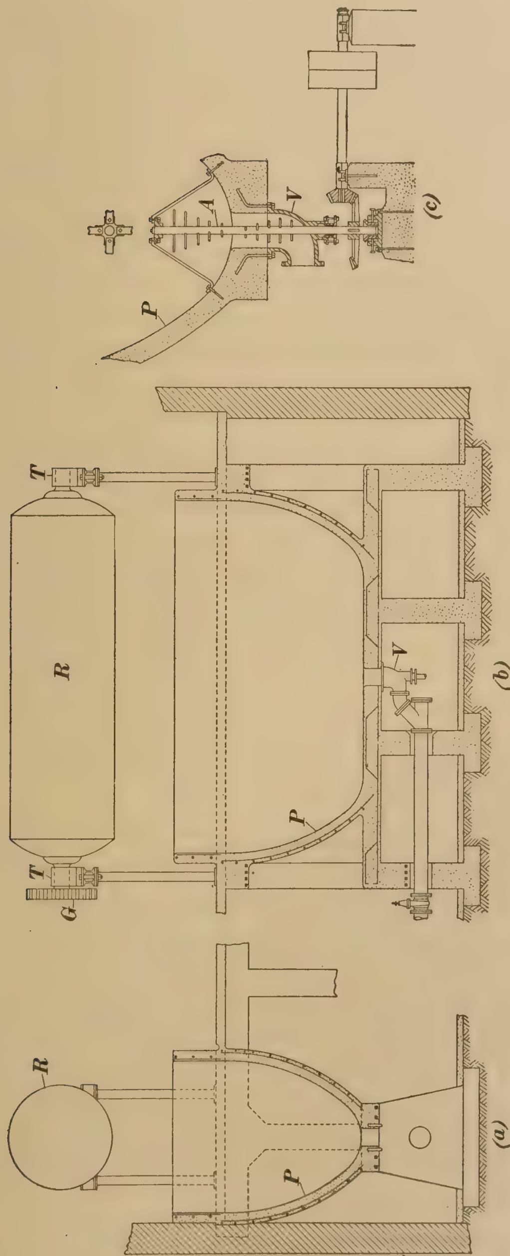


Fig. 12.

and *T*, the trunions, or bearings, one of which is hollow, for admitting steam; *G*, the motor driving gear; *P*, the dumping pit; *V*, the discharge connection. View (*c*) shows the agitator device *A*, used in modern pits for dumping of stock, and its drive.

68. Furnishing the Rotary.—After being discharged from the dusters onto a conveyor belt, the papers are delivered in a continuous stream to the manhole opening of the boiler. There is a difference of opinion in regard to the correct procedure for furnishing the papers and the liquor. In one mill, the practice is to furnish the papers first, packing them with long iron prodding rods; the liquor is then run in all over the papers. It is claimed that by this method the papers are more uniformly acted on by the liquor; also, opportunity is afforded for packing the papers, so they will not tend to float when the liquor is added, thereby decreasing the capacity of the boiler.

A second method in vogue is to furnish the papers and liquor together. In this way, it is thought that the papers are more thoroughly soaked with the liquor, and the possibility of a dry cook is overcome; also, the total time for filling the rotary is diminished, which is a valuable factor in costs and production.

A third method consists in running in the required volume of soda-ash solution first, and then furnishing the papers. The argument in favor of this method is that there will be absolutely no dry spots in the papers, and a much cleaner pulp will result, with a thorough cooking.

69. Amount and Strength of Liquor.—A rotary boiler 8 feet in diameter and 24 feet long is considered to be of the most efficient size for cooking old papers. A boiler of this size has a capacity of 1200 cu. ft., and it will hold from 5 to 7 tons of dry paper stock, depending on the grade and condition of the papers. Since the strength of the liquor used for cooking has never been standardized, the widest variation in this item is found in the different mills. Upon inquiry, one mill stated that they used water only as a detergent; another mill reported that they used lime and water; still another method in practice is dependent upon the action of a soap solution, together with a small quantity of free alkali.

70. An accurate statement from data received showed that another mill was using 3456 gallons of liquor per 10,000 pounds of paper; in this liquor was dissolved 1200 pounds of 58% soda ash

and 225 pounds of 76% caustic soda. These alkalis are dissolved in two tanks, each 7 feet in diameter and 7 feet deep, filled with water to a depth of 6 feet, the combined contents being used for one cook. These tanks are equipped with a cover (an opening $2\frac{1}{2}$ feet square being allowed for the introduction of the alkalis), agitator arms, and a steam injection pipe.

A further report from one of the largest mills treating waste paper stated that their consumption of soda ash amounted to 8% to 9% of the gross weight of the papers, as received in the sorting room. If an allowance of 10% be made for discards on sorting, this consumption would be at the rate of 9 pounds to 10 pounds of soda per 100 pounds of net sorted papers.

The lack of uniformity in the amounts of soda ash used for cooking paper stock is readily perceived from the figures stated, and no attempt has been made to standardize this figure. During the last few years, however, when the price of soda ash advanced to $3\frac{1}{2}$ to 5 cents per pound, this chemical was viewed with more respect, and efforts were made to reduce its consumption. Mills that formerly used 8% to 10% are now using 4% to 5%. Should the reduction stop at this latter figure, or is it possible to go still lower? Very careful experiments are being conducted at one or two mills to determine this safety point. Cooks have been made using 3%, with no bad effects; but this low figure is not to be considered as a criterion for a standard, since conditions are not always the same at all mills. Too many variables enter into the problem, which must be solved by each individual mill to suit its own equipment and conditions. It is to be hoped that with the adoption of standard cost methods, further research will be brought about in different mills, and that the results obtained will be interchanged more freely.

71. Amount of Water Used.—In standardizing rotary cooking, the volume of water used should be a known, constant figure. From inquiries made at numerous mills, only one had in practice a method of measuring the water. Many mills stated that they filled the rotary up to a *certain mark*, or else permitted a water line to be open for a certain length of time. Here, at least, is a step that can be taken in the direction of a standard for uniform operation—the installation of a water-measuring tank.

72. Rotary cooking accomplishes two things at the same time; *viz.*, de-fibering and de-inking. The de-inking has been

considered a chemical change, but it may also be classified as a physical change. The slow revolving motion of the rotary creates a tremendous amount of friction of surfaces, of attrition of particles of paper, and the combined action gradually separates the paper stock into its component parts—fiber, filler, size, and ink particles. With lapse of time, this action produces a colloidal solution, or suspension, of ink particles and fiber particles.

73. Increasing the Effect of Friction.—The question naturally arises—how can the friction between the inked surfaces of the paper be increased? Speeding up the number of revolutions per minute of the rotary may help, but only to the point where the stock gets the greatest tumbling action, and without clinging to the shell on account of the increased centrifugal force. Increasing the number of pins or angle bars may help; but it may have an adverse effect, if the rotary speed be not carefully worked out. The use of too much water will increase the slippage of the particles of stock upon one another, allowing the stuff to slip around without doing much de-fibering. Likewise, by not using sufficient water, danger of uncooked papers may be encountered. It would therefore appear that this factor in rotary cooking is a very important one; and careful supervision as to results obtained in using varying amounts of water will prove this statement. Cooked stock that is in a finely ground state, with particles not larger than a bean, and which has soaked up all the liquor possible to saturate it, with no residual unabsorbed or free liquor present, can be said to have had the proper consistency of paper and water during the cooking period.

74. Duration of Cook.—When the liquor and papers have been completely furnished, the manhole covers are bolted down and securely fastened. The steam is turned on and the rotary boiler is set in motion. A recent improvement in the construction of the rotaries provides for the regulation of the amount and frequency of the steam injections. An automatic valve is attached to the steam inlet, which operates and blows steam only when the pipes are submerged in liquor. The advantages of this arrangement are easily observed by the decrease in the amount of steam used, the more thorough cooking action, and the elimination of the possibility of scorching the papers with live steam.

75. Variation in the time of cooking and in the steam pressure used, is another feature of operations in different mills. The data received show that the cooking time varies from 1 to 10 hours, and that the steam pressure varies from 10 to 50 pounds. One mill recommends cooking 6 hours under 40 pounds pressure, while another mill cooks 10 hours under 50 pounds pressure. A mill that makes a very good grade of paper reports that a minimum of 7 hours is required for a good cook, and that 2 hours extra is allowed to reduce the pressure, blow off the liquor, and dump out the papers. The cooking in this case is conducted under 20 pounds pressure.

The variations here noted are attributable to the different procedures in practice. In the practical application of rotary cooking, it is generally conceded that there are three distinct factors that enter into the correct cooking of the papers. These factors are: (1) Volume and strength of cooking liquor per 100 pounds of paper to be cooked; (2) time allowed for cooking, exclusive of time necessary for blowing off pressure and dumping papers; (3) steam pressure used in cooking.

These three factors balance one another. If any one of the three be varied, the other two must be varied also, but in the reverse or opposite direction, to make the balance perfect again. The data received from the different mills establish the truth of this observation. One combination shows: 1494 pounds of soda ash in 3500 gallons of water per 10,000 pounds of papers, cooked 7 hours, at 20 pounds pressure; a second combination is: 14,000 pounds of papers, cooked 10 hours, at 50 pounds pressure, in a weak solution of soda ash.

76. Dumping, or Emptying, the Boilers.—The construction of the rotary boiler is so arranged that when the boiler is revolved and stopped, with the manholes facing downwards, the cooked papers discharge from the openings, the manhole covers having been removed. There is sufficient incline on the inside of the boiler to cause the papers to be removed almost entirely by gravity. The few remaining papers, if any, are raked out with a long-handled iron hook.

The papers are discharged below the rotaries into dumping or draining pits. Some of these pits, or tanks, are equipped with a perforated strainer, which allows the liquor to drain off into a separate catch pan, to be used over again, if desired, in making up the new liquor for the next cook. The dumping pit is

equipped with two washout valves, one draining valve, and one large outlet, for the removal of stock to the washers.

77. Recovery of Liquor.—The recovery of the soda-ash liquor used in rotary boilers is apparently lost sight of; but, inasmuch as the papers absorb most of the liquor, there is only a relatively small volume that freely drains off into the dumping pits. The papers treated in a rotary are reduced to a pulpy consistency, due to the continued rubbing and grinding action. The pulpy mass acts like a sponge, and will absorb and hold, by capillary attraction, a large volume of water; consequently, unless it is allowed to drain for a considerable period, the recovered liquor will be a small item.

The data collected on the recovery of the liquor gave results that varied from 11% to 50%, the general average being about 30%. One mill reported that they did not expect to recover any of the cooking liquor; it was worthless, in their opinion, and would merely discolor any fresh liquor that was made for new cooks. A second mill reported the average to be approximately 15%; and a third mill observed that the average was, roughly, 33%, or one-third of the liquor used.

78. A very enterprising mill stated that they had been *thinking* about this loss of soda ash for a number of years, but had done nothing definite to prevent it. They employed a chemist, who advised them further concerning the value of this waste, and they immediately took steps to provide a suitable drainer and catch pan for the liquor. In the dumping pits, the cooked papers are now subjected to a wash of warm water after as much as is possible of the cooking liquor has drained away. When the first wash water has drained off, a second wash water is applied; in this manner, the recovery was increased to 60%. Such efforts will pay, no doubt, when 8% to 10% of soda ash is used, and when the price of soda ash is high; but it is a very debatable question when only 3% of soda ash is used, as is now frequently the case. The cost entailed in saving the waste may be greater than the cost of the chemicals saved.

79. Spherical Boilers.—This type of cooker is operated in the same manner as the cylindrical type. An illustration of a spherical, or globe, boiler is given in Section 1 of this volume.

80. Power Required.—The manufacturers recommend the use of 8 h.p. for an 8 ft. × 24 ft. boiler; but actual practice has shown

that $4\frac{1}{2}$ h.p. is sufficient. One installation of this size of rotary calls for a 5 h.p. motor for each rotary, and the motor is seldom called on to approach its rating. The boiler revolves so slowly, about 1 revolution every 2 or $2\frac{1}{4}$ minutes, that the driving power required is small.

81. Furnishing Cooked Papers to Washers.—After the cooking liquor has drained off as much as possible, the papers are ready to be furnished to the washers, and this is effected in one mill by a very ingenious arrangement. It was previously stated that it required the combined efforts of six men to move the loaded cars of cooked papers to the washers when the open-tank method of cooking was used. In the mill here referred to, in which rotaries are used, the dumping pit is equipped with a dumping valve that leads into a vertical cylinder, about 3 feet deep and 2 feet in diameter, placed directly under the dumping pit and equipped with agitator propellor arms that are driven from a separate motor. The pulpy, cooked papers flow toward this cylinder, and they are hastened along by a water-pressure hose line. In the cylinder, they are agitated, to prevent any clogging of the pipe line through which the papers are pumped direct to the washers. This procedure effects a great saving in time, in labor, and in cleanliness of the cooking and washing rooms.

Fig. 12(*c*) shows a cross section of an agitator device *A* now in quite common use in the more modern mills; it is a very simple arrangement, and is entirely satisfactory in operation. A careful examination of the drawing is a sufficient explanation of the construction.

82. Remarks Concerning the Rotary Process.—The rotary process for cooking old-paper stock, and the dependent methods of handling the cooked papers, is regarded as the most convenient, the most efficient, and the most practical method in use. This view is held, in particular, by those mills that have rotaries in use or which expect to install them. While initial cost is considerable, the absence of steam and condensation and of the accumulation of papers and alkali liquors, the lessening of depreciation throughout the entire process, and the decrease in the labor cost attending the cooking and washing processes, are considered to be factors that more than counterbalance the extra first cost of installation. The entire process is more healthful to the workmen, and the cleanliness throughout appeals to all

who are familiar with other methods of treating waste papers. Some recent developments, however, have features which are strong arguments for the newer processes.

QUESTIONS

(1) State the advantages of a rotary boiler and explain the method of furnishing it.

(2) How much soda ash is commonly used per 100 lb. of paper cooked?

(3) Why is the amount of solution used so important?

(4) How does the rotary help to de-ink waste paper?

(5) What is the next step after the cooking is complete?

COOKING-ENGINE PROCESS

83. Description of Cooking Engine.—The **cooking engine** for waste papers is a machine of the type shown at *A*, Fig. 13; it is essentially a variation of the beater or washer described in

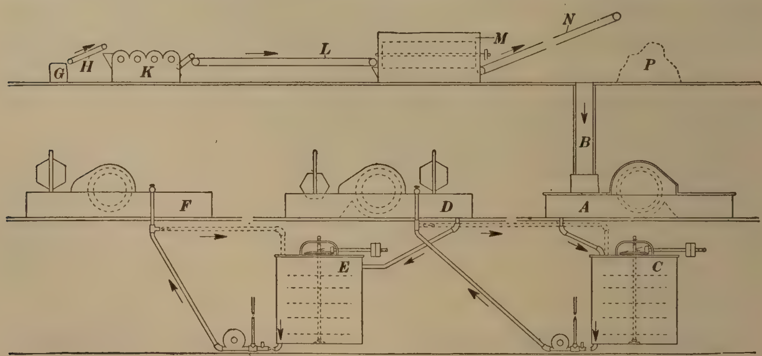


FIG. 13.

Sections 1 and 3 of this volume. An elliptical-shaped tub, about 8 ft. × 20 ft. and 3 feet deep, is divided down the center by a mid-feather, and in one side of the channel is a beater roll or propeller. The tub is covered as tightly as possible with steel plate, the end covers being hinged and held down by bolts or clamps.

Waste papers are prepared[1] as previously described; they are stored on the floor above or in bins, and are furnished by a chute *B*, Fig. 13. The cooking liquor, usually a dilute solution of soda ash,

[1] In Fig. 13, *G* is a bale of papers, *H* a belt conveyor, *K* a railroad duster, *L* a sorting conveyor, *M* a fan duster, *N* an inclined conveyor, *P* a pile of prepared stock.

is run into the engine *A* until the alkali content is equivalent to 10% of the weight of the papers that the engine can handle. This amount will fill the tub to a certain depth, say half full. The papers are then furnished and are circulated by the roll or paddle, and they are soaked with the liquor at the same time. Water is added as necessary, and more papers are fed in until the desired consistency, about 6%, is reached. A charge is about 1200 lb. of papers. While the charge is being furnished and washed, the contents are heated by steam, at full boiler pressure, for about 1½ hours. The agitation created during circulation de-fibers the paper and assists the chemical action of the liquor in loosening the ink particles, which are removed in the subsequent washing. The cooking time is about 2 hours, varying somewhat with the grade of the waste papers; old ledger and the like require a longer time to disintegrate. The power required is used almost entirely for circulation, and will average 25 to 30 h.p.

84. When the papers are thoroughly cooked and re-pulped, a valve is opened, and the pulped papers are allowed to flow into chests *C*, Fig. 13. No attempt is made to recover any of the cooking liquor, as it is considered not to have any value. The papers are furnished to the washers *D* by pumping from the chests *C* into which the papers were dumped after being cooked. After washing, the stock goes to chest *E*, from whence it is pumped to the beaters *F*.

85. Advantages of the Process.—The cooking engine process is claimed to have the following advantages: (1) Dusted papers are furnished from storage direct to engines; this provides for a storage always on hand, and it calls for a minimum of labor for furnishing. (2) Engines are covered tightly; this saves in steam and heat. (3) Papers are re-pulped better than in the old type of rotaries; this lessens the amount of work required later for beating and brushing out in washers and beaters. (4) Papers are thoroughly soaked in the cooking liquor; there is here no possibility of a dry cook. (5) Papers are handled by gravity, both before and after being cooked; this eliminates the hand labor—a costly item in the open-tank process. (6) Small labor cost throughout.

What may be called disadvantages or costly features are: (1) No recovery of the cooking liquor; this results in a large consumption of soda ash. (2) A large amount of steam is used; full

boiler pressure is maintained for $1\frac{1}{2}$ hours. (3) Large expenditure of power is required to circulate the papers. (4) The oil consumption and belting wear and tear is large; extra with belt-driven pulleys. (5) General wear and tear and depreciation are greater. (6) The pulp product is considered to be weaker; caused by the violent action of the steam, alkali, and the brushing action on the pulp. (7) Poor color of recovered pulp, compared with open-tank pulp, and not as good as rotary pulp.

A SEMI-MECHANICAL PROCESS

86. Treating Old-paper Stock Mechanically.—A new (patented) method has recently been perfected; it is in use in a few places, but has not as yet been completely adopted in the older mills. This method is largely mechanical in its action, and the details are illustrated in Figs. 14 and 15. The advent of this machine gave a wonderful impetus to the idea of treating paper stock mechanically. There is now quite a varied line of processes that might be thought to have originated from the idea of propeller de-fibering; these will be considered later.

87. Description of the Process.—This process was first brought to the attention of the general public in 1914–1915. Fig. 14 illustrates the design of the machine, which consists of an inner cylindrical tank A that leads, at its bottom, into a draft tube B, through which extends lengthwise a shaft F, to which are fixed two propellers C and C_1, spaced apart from each other, and of different pitch. The propellers, which are rotated at about 2000 r.p.m., draw the material downwards from tank A, drive it through tube B, and up through the course D at high velocity, estimated at 1200 ft. per min.

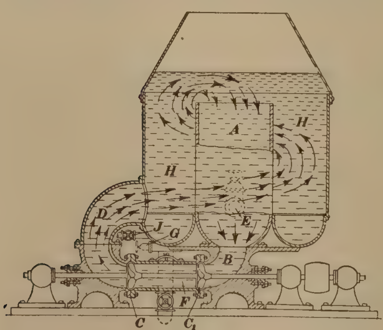


Fig. 14.

The course D discharges at a tangent into an outer chamber H, which surrounds the chamber A and is concentric with it. The material entering chamber H at a tangent circulates and rises spirally therein, as indicated by the arrows; it then cascades over

the upper edge of chamber A, and repeats its course of circulation through draft tube B, propellers C and C_1, and chamber H. The machine maintains a perfect circulation until all the stock is de-fibered. The stock is withdrawn from the apparatus through suitable pipes G, which lead from the mid length of the tube B and from the bottom of chamber H, as shown. During the feeding of the machine, water is supplied through pipe E, and steam for heating is admitted at intervals, as needed, through pipe J, shown below the course D.

The de-fibering action is due to the propellers C and C_1, which revolve so rapidly that the water is unable to take up the rotary speed thereof. Consequently, there are two opposing forces, one being caused by the speed of the propeller and the other by the inertia of the liquid and stock. In addition to these two de-fibering forces, there is another action, which may be described as the constructive and explosive effect on the fibers that is caused by the difference in the pitch of the two propellers C and C_1. The blades of propeller C have a greater pitch than those of propeller C_1, which creates a tendency to form a vacuum between the two propellers, thus producing what is described as an explosive or disintegrating effect on the stock.

88. De-inking Action.—As to the de-inking action, it appears that when wet paper that has been printed with ordinary black printers' ink is torn, any ink that is on the line of tear is much loosened by the pulling apart of the paper fibers; so much so, in fact, that the adhesion of such portions of the ink as remain on the fringes of disengaged fibers at the torn edges is much less than the normal adhesion of ink to untorn paper. This is probably due to the fact that the dry black ink is, physically, a species of film or incrustation, which sticks to the paper by reason of the adhesive properties of the ink, but which is capable of being mechanically loosened by the relative motions of the wet matted fibers to which it is stuck. Now if the paper be torn into such fine bits that the paper fiber foundation to which each particle of ink adheres, is wholly or partly pulled apart,—that is, if the paper is completely pulped or de-felted,—then this loosening action affects all the ink and renders it easy to remove.

89. Character of Paper Produced.—Obviously, some types and grades of paper stock can be reduced to a pulp more readily and with less deterioriation than others. A pulp made from a free

stock, in which the fibers in the original paper making were not greatly hydrated, is, of course, felted together rather than stuck together, and it is much more amenable to a disintegrating or de-felting action than a paper made of over-beaten or slow stock, in which the fibers are so much hydrated and glutinous that they are more or less welded together as well as felted. Extreme examples of such papers are pergamyn or glassine papers.

90. Method of Cooking.—The following statement was obtained from a superintendent who had one of these machines under his direct care and supervision:

"We are at present cooking with 5% soda ash, using about 900 pounds of stock to a batch, and we take about 50 minutes to a batch, the density of which is around 5%. While one batch is in process, we are softening another in the tank above, using the exhaust steam from the turbine for heating. We raise the temperature to 160°–180°F., never guessing at it, but always using a thermometer, as we get the best results in this way."

91. Cost of Operation.—This superintendent further states: "As to the cost of operation, this is, indeed, a hard matter to determine. There is, of course, a saving of about 3% in soda ash, as well as the saving of time in washing, which may counterbalance to some extent the extra power consumption. There is also a big difference in the cost of handling, which is quite an item in the vomiting process; in fact, I may venture to state that this item was responsible for the advent of the rotary. There is also to be considered the matter of the elimination of the dirty mess caused by the dripping of the alkali from the boxes, and the condensation caused during the cooking process."

It may be remarked that a 75-h.p. turbine has been specified for the satisfactory operation of the process.

92. Advantages and Disadvantages.—The chief objection to this process, which was later raised at the above mentioned mill, was its consumption of steam for power and heating. Even though the stock traveled 1200 ft. per min. in this machine, it was found that dead pockets of stock remained in the machine and were not acted upon, which resulted in dirty paper stock; this happened from oversight or carelessness in not getting the proper density (that is, the correct proportion of weight of papers and volume of water) in the tank. If the charge were too heavy on entering the machine, only that portion around the central tube

circulated freely. It has been suggested that the chamber H be divided by a helical passage, so arranged that the stock will circulate around and around the central tube until it finally comes to the top and splashes over into the central tube again, to begin its journey once more. If given proper attention by men who can regulate the stock to a uniform consistency, this machine will produce a product that can be readily washed, screened, and made into good paper. The color is a blue white, though not any bluer than stock produced by any other mechanical process, such as the rotary boiler or any of the later centrifugal-pump and tank systems.

93. The amount of steam consumed is that required to raise the temperature of the water in the de-fibering machine to 160°F., and for no other purpose; this represents approximately 300,000 B.t.u. per 100 pounds of paper.

94. Layout, and Sequence of Operations.—With the exception that no provision for bleaching need be made, and that the boiler capacity may be limited to that required for any new furnish and for mixing the recovered stock with this new furnish, the process just described uses substantially the same auxiliary apparatus as would be used in any other process that employs a mechanical pulper. The sequence of operations is as follows: According to their condition, the papers are first sorted by hand or are dusted in a duster and afterwards sorted; the first procedure is used when the papers are reasonably clean. The papers are then torn and are again dusted in a railroad duster or its equivalent. The torn papers are next conveyed upwards by a belt, apron, or an air conveyor to a soaking tank having an agitator, in which they are thoroughly wet in water at about 160°F. This tank A, Fig. 15, is so placed that it can quickly charge the de-fibering machine, which works in batches. The water in tank A is preferably heated by the exhaust from a steam turbine that drives the machine.

The de-fibering machine B, Fig. 15, is the next element in the layout, and its general principle has been already sufficiently described. Quick-opening valves must be provided for rapid charging and discharging; the time required for these operations being, even under the most favorable conditions, a considerable proportion of the total time of operation. The pulp from the machine passes to the de-inked stock chest C; it requires washing

only, or, at the most, washing and brushing out in the Jordan, to render it suitable for delivery to the stuff chest. The washing arrangements, indicated at D, are of the utmost importance for removing the loosened ink. The washing layout differs more or less in details, according to local conditions; but with an arrangement of ordinary efficiency, the pulp should be washed for about 2 hours. The pulp from the final tank will be of 3% to 5% consistency; it can usually be pumped to the paper-machine chest, if unmixed recovered stock is to be employed; or it may be pumped to the beater or other receptacle, in which it may be mixed with

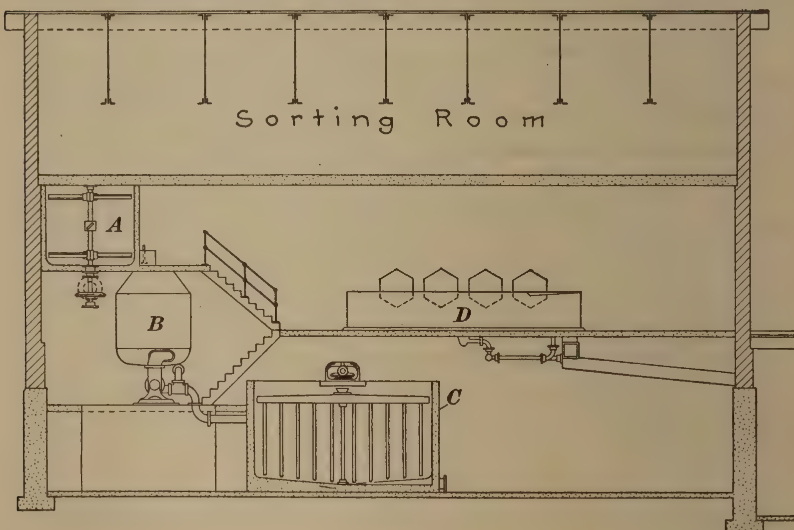


FIG. 15.

any new stock that is to be added. In some cases, it may be desirable to brush out the recovered stock in the Jordan before sending it to the stuff chest; the piping arrangements should be such that this can be done, or the Jordan should be by-passed, as conditions indicate.

Where magazine stock is treated, and sometimes in other cases also, it is advisable to pass the stock from the de-inked stock chest through a wire catcher, on the way to the washer. The washer may be an ordinary flat screen, or a long channel with dams, or a deep well. The well is made about 2 feet square and 25 feet deep, with a partition in the middle that reaches nearly to the bottom. The stock, diluted to about 1% consistency, is

fed at the top of one side, passes down, drops the pins, and is delivered near the top again.

95. Pulping Engine.—A pulping engine, which may be used in place of tank *A*, Fig. 15, in connection with the de-fibering machine just described, is shown in Fig. 16. This consists of an elliptical-shaped tub *A*, with midfeather *B*, in which the mixture of

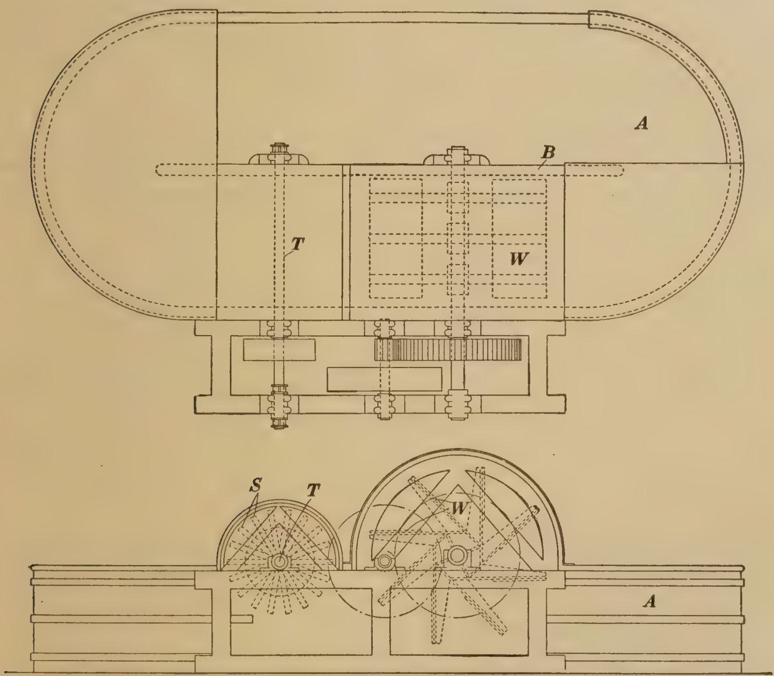


FIG. 16.

shredded papers and cooking liquor is circulated by a paddle wheel *W*, which makes about 19 r.p.m. The shaft *T*, which turns at 150 r.p.m., is studded with wooden slats *S*, which slash the paper into fragments and mix them with the liquor. One of these engines will hold 1700 pounds of paper, dry weight.

NEW TANK AND PUMPING SYSTEM

96. Remark.—During the World War, manufacturing methods and processes were given closer scrutiny than at any previous time. Work that required manual labor, and which had received

scant attention up to that time, possibly because of the abundance of willing workers at low wages, was supplanted by machinery and mechanical processes. It is therefore not strange that this change also occurred in the processes for the conversion of old-paper stock. After the introduction of the de-fibering process just described, many applications were made of the idea of de-inking and de-fibering paper stock by propelling and circulating with centrifugal pumps, and by impinging the stock and water against a plane surface, a conical surface, a Y or T surface, or even against itself, in divided streams.

97. Improved Cooking System.—One very enterprising mill that formerly used the open-tank system has installed a new system, which not only saves 50% of the building space, a very

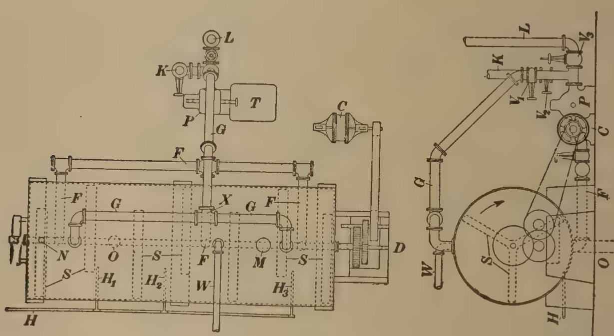


FIG. 17.

important item in costs, but also effects a saving of 50% in soda ash, and saves the services of 28 men and 30 women. This change was effected by using the old tanks in the new construction, by installation of the carrier system of sorting, and by combining what were formerly two sorting rooms and two cooking rooms into one sorting room and one cooking room.

Fig. 17 represents one of four similar cooking tanks, each 10 feet in diameter and 26 feet in length, suitably mounted on concrete piers. Each tank is equipped with a specially designed agitator, having arms *S*, which are staggered on the central shaft and are so arranged that complete agitation is assured at a speed of 10 r.p.m. The agitator is belt driven, and the power is furnished by individual 10-h.p. motors; the motor and the agitator drive are shown at *C* and *D*. Although 10-h.p. motors are used, actual

tests indicate that 3.5 to 5-h.p. is sufficient; but for safe working, it was deemed advisable to have a motor of sufficient power to take care of any unusual condition that might develop, as when more than 7500 pounds of paper stock is cooked and agitated at an increased density.

98. Method of Operation.—The paper stock, which has been previously dusted and shredded into pieces 2 inches square, is blown through an 18-inch diameter air duct from the sorting room into the charging manhole, shown at *M*, Fig. 17. To allow the escape of air during the charging, a vent *N* is provided at the other end of the tank. A 6-inch water pipe *W* supplies water to each tank while 6500 to 7500 pounds of stock is being introduced. Soda ash to the amount of 4%, based on the dry weight of the paper stock charge, is dissolved in the soda-ash tank, which is located where convenient, but preferably on the floor above the cookers. The filling operation takes from 20 to 30 minutes. The temperature of cooking is maintained at 200°F., so that the consumption of steam is not so great as in the open-tank or rotary-boiler processes. The steam inlets are shown at H, H_1, H_2, and H_3; they are made of $\frac{3}{4}$-inch piping, reduced from a $1\frac{1}{2}$-inch line, on which the valve is located. When properly filled with paper and water, the stock should have a consistency of 8%.

99. De-fibering and De-inking.—The de-fibering and de-inking of the stock are effected by an 8-inch centrifugal pump *P*, direct-connected to a 40-h.p. motor *T*. The pump is especially designed for this work; it has impellers of sufficient rigidity, and is constructed to de-fiber and circulate, without plugging, at a speed of 1700 r.p.m. Under the heaviest loads, 36 h.p. is required to operate the pump, but the average for 30 days was only 18 h.p. However, when it is necessary for the pump to take up peak loads, such as an extra heavy wad or slug of stock, the extra power then needed is available.

100. The circulation of the stock is effected by means of 3 8-inch pipe lines *F*, which lead to the pump inlet, and by 2 8-inch pipe lines *G*, which lead from the pump discharge back to the cooking tank. The pipes *G* conduct back to the top of the tank the stock that impinges on the T connection, shown at *X*, where further de-fibering takes place. The T connection is considered to hasten the preparation of the stock, because of the friction

and the churning that the mixture of paper and water receives at this point.

After circulating, de-fibering and cooking for one hour at a temperature of 200°F., the papers are considered to be cooked. By opening valve V_2 or V_3 and closing V_1, the cooked stock is conducted by lines K or L to storage tanks, not shown in the figure. From 20 to 30 minutes is required to empty the cooking tank. The process consumes 30 minutes for filling, 60 minutes for cooking, and 30 minutes for dumping, a total of 2 hours, for 6500 to 7500 pounds of de-fibered stock. This compares very favorably with 5 to 10 hours for cooking 5000 to 6000 pounds of papers in the open-tank process.

101. Fewer Employes than with Open-Tank System.—A comparison of the labor employed with the improved system with that employed with the open-tank system shows that the improved system will do the combined work of two sorting rooms used with the open-tank process. Specifically, the old system requires 2 rooms for sorting on the bench method; 2 foremen; 6 carrier men, for emptying barrels onto conveyors; 4 truckers, for trucking barrels of sorted papers from benches to conveyors; 6 cook-room men, 2 to make soda ash and 4 to fill open tanks with papers; 4 unloader men, to remove cooked stock from tanks with pitchforks; 2 washer rooms, with 4 men in each room; 24 washer men, 8 men on each tour, to fill washers by forking stock from small cars; 60 sorting girls. This shows a total of 54 men and 60 women.

The improved system requires only 1 room for sorting 60 tons of paper; the conveyor system replaces the bench method of handling the papers; and there is required: 1 foreman; 3 floormen, to truck, lay down, and open bales at the conveyors; 2 cook-room men, 1 to make soda ash and regulate steam and water, and 1 to fill and discharge cookers and to pump stock; 12 washer men, 4 men on tour in 2 rooms (2 men for each tour); 30 sorting girls. This shows a total of 18 men and 30 women, which is a reduction of 36 men and 30 women as compared with the open-tank system. A saving of two-thirds the number of men and one-half the number of women formerly required to produce the same tonnage, is a marked step forward in lowering manufacturing costs. The improved system is a distinct credit to the mill employing it, and unstinted praise is due to the superintendent who planned and worked out the process.

102. Digester Method of Cooking, De-inking, and De-fibering Old Waste Papers.—The cooking of old waste-paper stock, such as old magazines, books, ledgers, and material of this kind, free from groundwood, in digesters is of but recent origin, and it adds another method of recovering this class of material to the several well-known systems already in use and so well described in the preceding pages. No new principles as regards the actual process are used, however, neither is any secret process employed; and whatever explanations have been given to explain the principles of de-inking will apply to the present method of treating old waste paper.

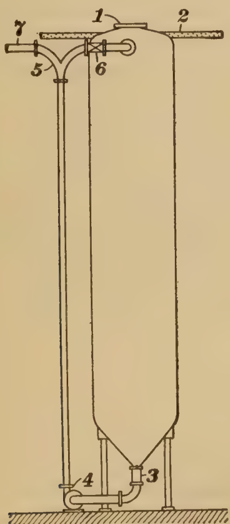


FIG. 18.

In this system, the type of digester used for cooking old papers is essentially the same sort of vessel that is used for cooking wood pulp in the soda process, with the exception that no auxiliary equipment, such as a steam condenser, as used in the soda process, is necessary. The digester is a cylindrical steel vessel, approximately 21 feet high by five feet internal diameter, the ends being rounded, cone shaped, or having some other form of smooth convex bottom. It is very important that a design be chosen that will eliminate the possibility of the stock's sticking to the sides of the digester. One mill using this type of equipment considers it advisable to keep the diameter rather small in proportion to the height; this, they believe, provides a more

uniform circulation, which is very essential if a uniformly cooked pulp is to be obtained.

No lining is required, since the weak cooking solution of soda ash does not attack the metal. To reduce radiation losses, however, the digester is covered on the outside with suitable heat-insulating material. The digester stands in an upright position and is supported on columns, which are fastened to brackets that are attached to the convex bottom. At the upper end, Fig. 18, is an opening, or manhole, 1, approximately 20 inches in diameter, through which the shredded old papers are charged into the digester, either from storage bins above or from the working floor 2, which is on a level with the top of the digester. A hinged cover is provided, with an atmospheric relief valve attached, to prevent the escape of steam vapors during the process of cooking. The atmospheric relief valve is simply a device to prevent the building up of a greater pressure than 1 or 2 pounds per square inch. To the apex of the lower section of the digester, which is shaped like an inverted cone, is bolted a 10-inch long-sweep flanged elbow, which connects valve 3 with a specially designed, single-suction, centrifugal stock pump 4. This pump de-fibers, de-inks, and circulates the stock in the digester, and is provided with a specially constructed impeller to prevent plugging. Both the suction and discharge ends of the pump are provided with quick removable fittings, which can easily be opened up to remove any obstruction that may have entered unnoticed with the papers when filling the digester. The vertical discharge pipe, leading from the de-fibering pump, enters at a point near the top, about 1 foot above the level of the contents of the digester when completely filled, and at an angle that will impart a swirling motion to the stock, thereby aiding in the thorough mixing of the pulp. The vertical pipe has a Y, 5, and valve 6, to direct cooked stock through valve 7 to the storage tanks.

To overcome the tendency of the papers to bunch, thus stopping the impeller, during the initial stages of cooking, to permit smaller pump clearances, and to decrease the time of filling the digester, one mill has installed a breaker beater on the floor above the top of the digester, and all papers are given a preliminary breaking up in warm water, at a density as high as possible, before they are fed into the digesters. Under the heaviest loads, only 25 h.p. is required to operate the pump, and this for only very short intervals, as the average running requirements

take 20 h.p. It is necessary, however, to provide a margin to care for the peak loads, such as when an extra-heavy wad of paper or slug of stock enters the pump.

103. Method of Operation.—A measured quantity of hot water at a temperature of 180°F., to give a concentration of 6% to 7%, is first run into the digester from a hot-water storage tank above, and the de-fibering pump is set in motion before any papers are thrown into the cooker. Then 1350 pounds of dry paper, which has previously been dusted and shredded into small pieces, is gradually thrown into the cooker by the operator. This operation must be attended to with care, as too great a speed of filling will result in the papers' forming into a ball and dropping to the suction of the pump. The time of filling takes an average of 30 minutes when done in this way; however, when a breaker beater is used to prepare the stock before charging, 3 to 5 minutes is all that is required. While the digester is being filled with papers, 80 pounds of soda ash (which is approximately 6% by weight of the dry weight of the papers used per batch) is charged along with the papers into the digester, either thrown in, in dry form, or run in in solution. Experience has taught that this amount of soda ash will thoroughly cook 1350 pounds of ordinary soft-sized papers, such as magazines and book papers. Some adjustments, however, are necessary from time to time, as the qualities of papers vary considerably. In some cases, this amount of alkali may be excessive; but it is not considered good practice to reduce this amount very much, since one batch of undercooked papers would more than offset any lowering in the cost that might result from the saving of a few pounds of soda ash.

When the digester has been charged, the cover is fastened down, and either live steam or exhaust steam is turned into the mixture to bring the temperature up to within a few degrees of the boiling point, and to hold the temperature at that point throughout the entire cooking time. The de-fibering and cooking operation is then continued for 2½ hours, when the process is considered complete. In some installations, the temperature is controlled by means of a thermostat valve, while an atmospheric relief valve keeps a pressure from building up. The small amount of steam required—about 400 pounds per 100 pounds of papers cooked—does not, by condensation, appreciably change the consistency of the charge.

Before the digester is emptied, however, a few samples of the stock are withdrawn and washed by hand on a small test plate, which is nothing more than a small screen made of Fourdrinier wire. If the test reveals small pieces of un-de-fibered paper with ink particles attached, the process is continued longer, until another test indicates that the cooking and de-fibering are complete. Valve 6 is then closed, valve 7 is opened, and the contents of the digester is pumped over into a storage chest; from there, it is pumped to the screens and washers, to be treated as described in Arts. **107–111.**

104. Advantages and Disadvantages.—The big disadvantage in a system of this kind is the care that must be exercised in filling the digester. Carelessness on the part of the operator may clog the pump and give a great deal of trouble, with consequent loss in production, possibly at a time when most needed. Where a beater is used in conjunction with the digesters, this trouble is avoided. A large amount of steam is employed as compared to that used with the rotary system; but this can be kept at a minimum if the maximum charge is put into the digester each time. The ratio of paper to the amount of water used is very important, if the amount of heat required is to be kept to a minimum; and efforts should be made to obtain hot water with waste heat.

The advantages claimed for this system of cooking are as follows: (1) Dusted and shredded papers can be furnished direct from storage and with a minimum of labor, only one man being required; (2) cookers are totally enclosed, thus presenting a neat and clean appearance; (3) papers are re-pulped better than in rotaries, and they are not given an unnecessary amount of brushing; (4) papers are uniformly de-fibered throughout—there is no possibility that any pieces of dry paper, with ink particles attached, will remain un-de-fibered and enter the furnish of the finished product; (5) papers are handled by gravity, both before and after cooking—this makes for a small labor cost.

USE OF WASTE PAPERS FOR MAKING BOARDS

105. Use of Discards.—There is much waste paper collected that cannot be made into white paper; to this must be added the discards from the sorting processes previously described. Still, even this low-grade material is graded for special uses; it is highly

valued for test board and wrapping paper and in the manufacture of kraft paper. Other grades of discards, including old box boards, etc., go into pasteboards, card middles, and similar papers. Less care is required in sorting discards, and they are very often furnished direct to the beaters.

QUESTIONS

(1) Describe the cooking engine.

(2) Would you consider it worth while to recover the chemical used in cooking by the process described in Art. **87**? Give reasons for your reply.

(3) Upon what principle does the mechanical de-inking of paper by the process of Art. **87** depend?

(4) If 5% of soda ash is required for a batch of 900 lb. of papers, what is the weight of soda ash required? *Ans.* 45 lb.

(5) How is the de-fibering and de-inking of stock effected by the process described in Arts. **99** and **100**?

(6) Referring to Fig. 17, explain briefly the operation of the apparatus there illustrated.

(7) Mention some of the advantages that the improved system has as compared with the open-tank system.

TREATMENT OF COOKED PAPER STOCK

WASHING THE STOCK

106. The Third Step.—The third very important step in the treatment of waste papers pertains to the washing and the subsequent bleaching of the cooked paper stock.

107. Washing Engine.—Many different methods are used in washing the papers, the most general process being that in which washing engines are used. These engines, fully described in Section 1, consist of a beater-shaped tub, a circulating roll that is equipped with blunt steel knives, but without a bed plate, and 2 to 4 octagonal-drum washing cylinders (see Figs. 11 and 12, Section 1).

The capacity of this type of beater is from 800 pounds to 2000 pounds, the average being about 1600 pounds. The circulating roll is raised or lowered by means of a worm gear, in order to vary the slight brushing action that the stock receives. By installing a bed plate and using sharper knives, these washers can be readily converted into beating engines. The octagonal-drum washing

cylinders are constructed on the usual bucket arrangement pattern. The faces of the cylinders are first covered with $\frac{1}{4}$-inch mesh facing wire, and are topped with 60- or 70-mesh washer wire. It has been the custom heretofore to use only old Fourdrinier-machine wire for facing the cylinder; but experiment has proved that a larger screening surface is obtained by using the larger $\frac{1}{4}$-inch mesh wire for facing, and covering this with wire that has been woven especially for the washing of stock. Nickel-alloy 60-mesh wires have been placed on the washing drums; and, after $1\frac{1}{2}$ years of service, they have shown no perceptible wear. They do not require any scouring out with acid, and, barring accident from puncture, they should have a much longer life than this. The cylinders are equipped with a raising and lowering ratchet wheel.

108. Operations.—After being thoroughly cooked, the papers are furnished to the washers, either from the chest *C*, Fig. 15, or as described in Art. **81.** Sometimes 2 or 3 quarts of kerosene is added; this keeps down the froth and foam that will otherwise result when the saponification products (soaps) of the cooking process, which have been absorbed by the papers, come in contact with the washing cylinders and the rapidly revolving circulating roll. When the washer has been completely furnished, the washing cylinders are lowered and the wash water is turned on. The amount of water used is regulated to correspond to the volume removed by the cylinders; thus a continuous stream of fresh, clear water is being added to compensate for the water removed, which is laden with the soluble saponification products, ink, and dirt particles.

In this type of machine, the fresh water is admitted to the stock, sometimes at the bottom of the washer and in back of the roll, through a 6-inch pipe. This water dilutes the stock, passes up through it and out by the revolving cylinders, and goes to waste. Sometimes the water is introduced in front of the roll, which mixes it with the stock. It is a slow process of constant dilution of the impurities of the cooking action, and a large volume of wash water is required. This same volume of wash water, if applied to the stock in batches of equal amounts and then removed, thickening the stock after each addition of fresh water, would greatly lessen the time of washing and would produce a cleaner pulp.

109. Removal of Dirt.—By the constant dilution of the dirt, the amount of dirt remaining in the pulp is gradually lessened. This progressive action continues indefinitely; but, even after the stated washing period has expired, the stock still contains dirt, though, of course, only a very small amount. If at this point, a sample of stock be taken from the washer and subjected to a stream of fresh water on a small hand screen, the stock will brighten up at once to a snow-white color. It is this principle that has been taken advantage of in the modern continuous washer.

110. Removal of Carbon of Inks.—If the paper stock has been thoroughly cooked, the carbon of the inks is readily removed. In the open-tank process, the papers still retain, largely, their original flat shape after cooking; hence, on immersing a sheet of cooked paper in water, the individual letters of solid carbon can be loosened from the paper by gently moving the sheet to and fro. The same result is obtained in the cooking engine by the action of the roll on the papers, the friction of the papers against the sides and bottom of the tub, and against the cylinders; the continual rubbing and friction in the mass also further the removal of the inks and the formation of an emulsion, which is readily removed in the wash water.

For the first hour of washing, the wash water is very muddy and dirty. Continued washing clears the stock; and the color gradually changes from the heavy gray tone to a blue white, for ledger stock, or to a cream white or ocher tint, for book or magazine stock.

111. Duration of, and Effect of, Washing.—The time required for a thorough washing depends on a number of factors. The degree of cooking that the paper has received must first be considered. If well cooked, the inks will readily emulsify with the water ; but if the paper has not been completely cooked, the ink still sticks, or perhaps it may loosen from the surface of the paper and be found later in the finished paper. If the papers are dry cooked, no amount of washing will clear the ink from the pulp; and after being bleached, this product has a light grayish tone, similar to the color of newspapers.

112. The second factor to be considered is the nature of the printing inks. It has been found that ordinary book and maga-

zine inks and colors are easily washed out; but lithograph and label papers that contain waterproof inks and varnishes, present greater difficulties. Solid ledger papers are easily washed out; they have received a harder treatment in cooking to dissolve the hard sizing, the inks readily emulsify, and a clear, blue-white pulp is obtained with about $2\frac{1}{2}$ hours of washing, $\frac{1}{2}$ hour for bleaching, and $\frac{1}{2}$ to 1 hour for removing bleach residues.

113. The third factor to receive consideration is the composition of the papers to be washed. Long-fibered stock, such as writing and ledgers, requires a much shorter washing period than the short-fibered book stock. The fourth factor is the circulation

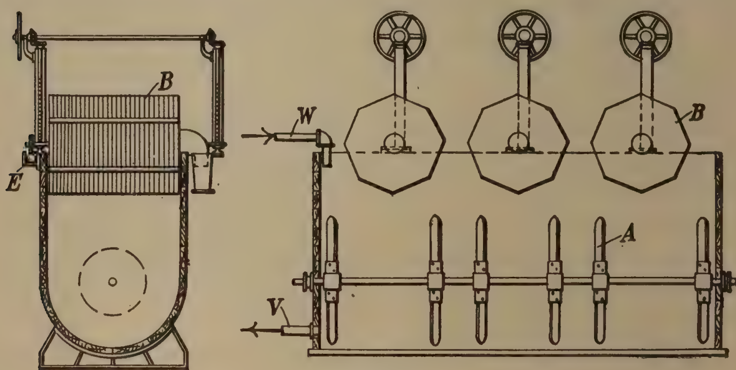


FIG. 19.

of the stuff in the washer and the amount of water used, which influences the washing period. The third and fourth factors are really dependent on each other, for the larger the volume of water the faster the stuff will circulate, and the larger the volume of water used the greater will be the amount of dirt and ink removed in a shorter period.

114. When the paper stock is considered to have been washed long enough, a sample of the wash water is taken out and examined. If the water is clear, the pulp is ready for bleaching; but if the water is still cloudy, if a grayish sediment is noticed, the washing must continue until clear fresh water is obtained. The first washing will generally take from 3 to $3\frac{1}{2}$ hours for the usual run of paper stock, such as book and magazine.

Before bleaching, it is well to concentrate the stock by shutting off the water, but letting the cylinders run for a time.

115. Other Forms of Washers.—In Fig. 19 is shown a machine that both washes and concentrates. The agitators *A* keep the stock well mixed, and the rotating dippers *B*, which are covered with wire mesh (60-mesh over 14-mesh), take out the dirty water as fresh water is added at *W*. On shutting off the fresh water, the stock is concentrated, thus saving bleach and storage space. This washer handles 1500 pounds of waste-paper stock at 3% to 4% in from 2 to 3 hours; it requires about 6 h.p. to operate it. Each washing cylinder *B* is driven at 8 r.p.m. by a worm gear from a shaft *E*. The washed stock is removed at *V*.

116. Another type of washer, which is meeting with some favor, is a slightly inclined, slowly rotating cylinder *C* of fine wire cloth, shown in Fig. 20. The stock is fed in at one end and is distributed by worm *W*; and as the dirty water drains out, the fibers are washed with showers, *S*, finally emerging at the other end. Very little power is required to operate either of the washers

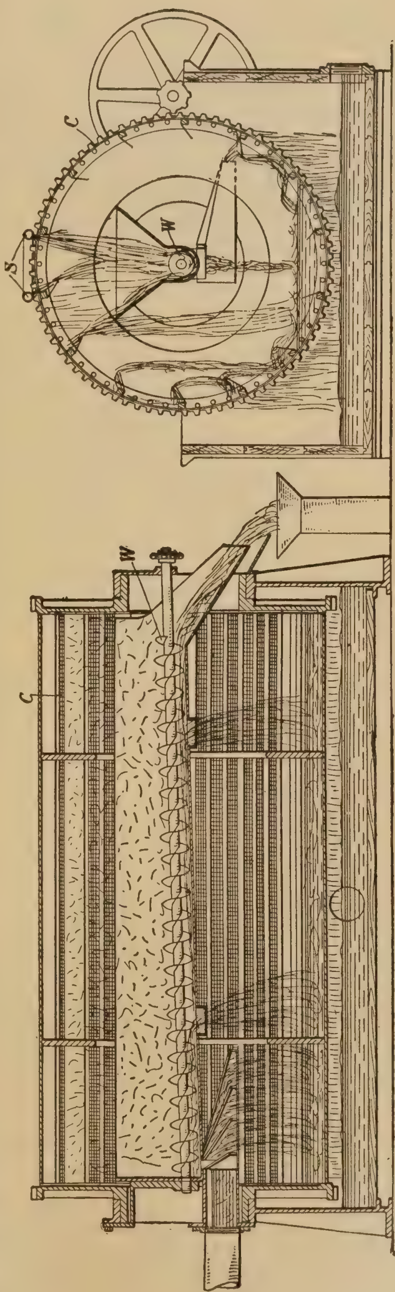


FIG. 20.

just described; but practical men consider them to be wasteful of stock.

117. A new type of washer, which is giving good results, is shown in Fig. 21; this washer is very effective for washing thick stock rapidly. It is better to wash stock when it is thick, if the water can be removed; because, first, there is less stock lost, and, second, on account of the small amount of water in the stock, a given quantity of water added or removed produces a greater effect.

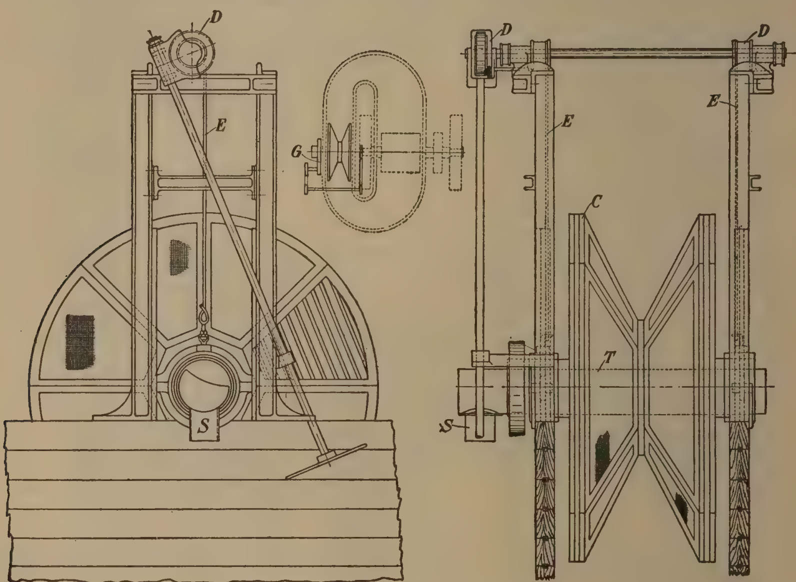
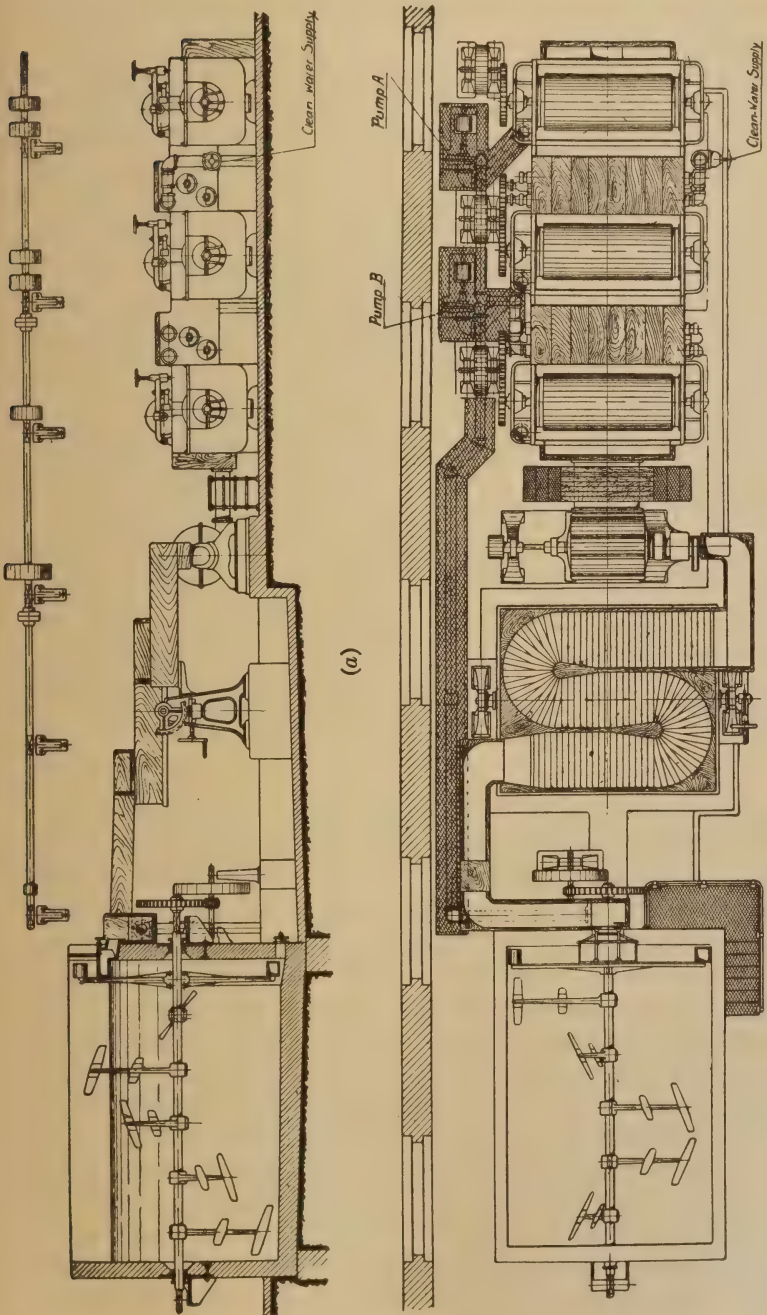


FIG. 21.

S (Fig. 21) is a spout through which dirty water is discharged from the hollow shaft *T* at the center of the cylinder *C*; *D* is a worm gear for lifting the washing cylinder by means of cables *E*. This washer was developed as a feature of the beater shown in Fig. 3, which is also used as a washer and bleacher; it circulates stock of unusually high consistency. The small view shows the assembled washer, in which *G* is the gear, belt driven from the beater-roll shaft.

118. A Three-Cylinder Washer.—The tendency to take advantage of a continuous process has become well marked in waste-paper recovery; and much attention has been given to the



(a)

(b)

Fig. 22.

three-cylinder washer, which authorities regard as the ideal type of washing machine.

An improved washing system for removing ink from cooked waste papers is shown in Fig. 22, (*a*) being a side view and (*b*) a top view. The arrangement consists of a horizontal stuff chest, from which the stock is lifted at a uniform rate by means of a bucket wheel; a gravitator (or sand trap), the feed to which is controlled by a gate; a centrifugal screen, for removing the dirt not caught in the gravitator; and a washing machine, which comprises three cylinder units. The cylinder in each unit picks up a layer of stock in the same manner as a pulp thickener, and delivers it to a couch roll, from which it is scraped and passed to the next unit.

The water consumption is small, by reason of the economical way in which the water is handled, and 80% to 90% of the ink is removed in the first cylinder; this water is not again used for washing. The water from the second cylinder is pumped to the stuff chest by pump *B*, where it is used for thinning the stock delivered by the buckets. The water from the third cylinder, which is, of course, the cleanest, is pumped into the first agitating trough by pump *A*, and is there used as thinning water. The only place where clean fresh water is used is in the final washing operation, which occurs in the last agitating trough.

BLEACHING THE STOCK

119. Consumption of Bleach.—After washing, the recovered pulp is ready to be bleached. For a washing engine of 1600 pounds capacity, about 60 to 70 gallons of bleach liquor is used for book and magazine stock. The liquor should test 6°Tw. at 60°F., which is equivalent to about $\frac{1}{2}$ pound of bleaching powder to a gallon of liquor; this amounts to 2 to 3 pounds of powder to 100 pounds of dry papers. This volume of bleach liquor is allowed to act, without heating the pulp, for 30 to 45 minutes, and it should produce a snow-white pulp. By taking the chill off the water and raising the temperature to about 80° or 90°F. (never higher than this), the bleaching operation may be greatly shortened. It has been found by trial that a warm bleaching of 15 or 20 minutes' duration produces very efficient results. It has also been demonstrated that, when necessary,—such an occasion arose during the World War,—a good bleached pulp can be produced with 0.6

pounds of bleaching powder per 100 pounds of papers; this amount, however, did not give the product the white tone that may be obtained with a larger consumption.

After giving the bleach sufficient time to act, fresh water is turned in, the cylinders are lowered, and the bleach residues are completely washed out. To test for the complete extraction of the bleach, the well-known test of starch and potassium iodide is applied to the washed pulp; any chlorine that may be present will be revealed by a distinct blue tint.

120. Bleaching Stock from Special Papers.—For bleaching ledger stock, about 35 to 40 gallons of bleach solution for 10,000 pounds of paper is required, depending on the quality of the paper. A thoroughly washed, solid ledger stock presents a fine blue-white appearance, even before the introduction of the bleach solution. The mixed ledger, which consists of letterheads, invoices, bills, letters, and other similar papers, presents a motley array of colors, and it requires a thorough bleaching; but, even then, the resulting pulp has a faint tone, dependent on the proportion of the strongest-colored stock present. However, with the exception of the heavier mineral colors, such as chrome-yellows, oranges, greens, umbers, and ochers, the colors are easily removed with 40 to 50 gallons of bleach liquor. The bleaching of this grade of stock requires from 45 to 60 minutes to obtain the best results.

121. Variation in Color of Bleached Pulp.—It is quite impossible to obtain a strictly uniform color in the bleached paper stock. There is such a wide variation in the composition of the papers treated, in the many different colors present, and the variation in the degree of cooking in different parts of the open tanks, that this difference is to be expected. A simple expedient, used in many mills to obtain a good sample for matching pulp from beater to beater, is the following: A sample of pulp is taken from the beater and pressed with the hands into a ball, about the size of a baseball. With practice, it is very simple so to press all the sample balls that each will have very nearly the same percentage of moisture. By breaking a ball into halves and comparing one half with a half from another ball, a good idea of the variation between the two may be obtained. (When comparing two pulps, it is very important that both have the same moisture content.) These balls can be stored on a shelf, marked

with the beater number and the time, and can then be inspected later by the superintendent and foreman, if this is desired.

It is the practice in one mill to dump the bleached stock, together with the bleached residues, into tanks, from whence it is pumped up over the screens and back to the drainers (see Fig. 15, Section 1), where the stock is allowed to remain until all the surplus liquor drains away and the drainer is filled. In this way, the bleach residues have an opportunity to become dissipated while oxidizing any organic coloring matter that may still remain in the stock. The door to the drainer is then opened, the pulp is forked into cars or containers, and is furnished to the beaters. When taking stock out of the drainers, it is removed in vertical sections, so that the various tinted strata of stock may be kept uniform in all the beaters furnished. In this way, it is simple to keep the shade of the finished paper constant. If the pulp is put into the drainer hot, the color will surely deteriorate. It is best to wash the pulp in the bleacher.

122. Use of Wet Machine.—Another method in vogue is to run the washed, bleached, and screened stock over a wet machine (fully described in Section 1) and into laps of pulp of about 25% to 30% air-dry fiber; the laps are stored according to the grade of paper and the resultant shade. This method of handling screened pulp possesses many advantages, and was adopted by one of the most modern book-paper mills; it is considered to be the most economical and efficient method in use, for the following reasons: no elaborate pumping systems or storage tanks are required; the loss of time in furnishing the beaters with diluted pulp is eliminated; the wet machine can be run independently of the grade of stock being used; the storage of the pulp ahead of the beaters, and the possibility of an immediate change from one grade of paper stock to another, is a wonderful saving and improvement; the ease and exactness with which the color or shade of the paper made on the machine is maintained.

SHRINKAGE OF COOKED PAPERS ON WASHING

123. Amount of Shrinkage.—The shrinkage of paper stock on washing has always been a stumbling block for many mills that have considered the adoption of cooked paper stock for a part of their pulp requirements. The exact per cent of shrinkage has, perhaps, never been worked out under actual mill-working

conditions; but it has been estimated to range from 20% to 40%. If the paper treated is all coated paper, practically all the coating is removed by the de-fibering and washing of the stock, and a shrinkage of 40% will probably result, but this does not include the loss of any filler that may be present in the raw stock before the coating was applied, which amounts to 5% to 8% additional. Toward the end of the washing process, that is, when the wash liquor is free from dirt and contains only short fibers, it is usually considered that an additional loss of 1% occurs for every added 15 minutes of washing. Therefore, it is not advisable to wash any longer than is necessary to get standard color.

Machine-made paper has usually received a thorough beating or refining treatment. The individual fibers have been drawn out and cut up in the beaters, and the refining engine again reduces the length of the fibers, when necessary. Then, too, bleached soda pulp is quite generally used, much of which consists of fine or short fibers. There is no way of preventing the loss of most of this fine-filling fiber, if the stock is thoroughly de-fibered and washed through the 70-mesh washing cylinder wire.

124. Limits of Shrinkage.—Numerous ash tests have been made on the completely washed and bleached paper stock, and the results vary from 2.5% to 4% total ash. When this percentage is compared with the coating ingredients of paper, which amount to from 30% to 40% of the weight of the paper, the shrinkage is well nigh startling.

Books and magazines are usually printed on supercalendered paper, which contains 15% to 20% ash. The loss in ash alone (not reckoning the 20% of bleached soda fiber that is usually present) thus varies from 15%–20% to 2.5%–4% which shows, perhaps, the lowest minimum shrinkage. In solid ledger stock, the shrinkage is largely equivalent to the loss of the heavy sizing—both animal and rosin sizing—because the stock is usually 80% to 100% rags, which have a long fiber. The remainder of the fiber composition is long-fiber sulphite, which does not entail a great loss.

It is safe to say that the average loss in washing of all kinds of paper, well mixed, will be 20% to 30%.

SCREENING WASHED AND BLEACHED PAPER STOCK

125. Importance of Screening.—After the old paper stock has been washed, bleached, and dumped into storage tanks, it is ready

to be screened, which is the fourth very important step in the treatment of waste papers, although it is an almost forgotten detail in some mills.

126. Common Form of Screen.—The usual screening system in American mills is exceedingly simple, and it is frequently inadequate. One flat diaphragm screen of six plates, each plate 12 inches wide and 40 inches long, is considered sufficient to screen stock for three beaters of 1000 pounds capacity. About 3.5 h.p. is required to drive a screen of this type. The stock is pumped up from the storage tanks, at a consistency of about 3.5 ounces per gallon (equivalent to 2.66%), onto sand traps. (For disinfection of screens, see Section 7, Vol. III, and Section 1, Vol. V.)

127. Sand Traps.—A common sand trap is 24 inches wide, 30 to 40 feet long, and 12 inches deep; it is placed 8 to 10 feet above the beater-room floor, thus allowing free passage underneath. The bottom of the sand trap is lined with canvas, such as old cotton dryer felt from the paper machine, or is fitted with cross dams.

The purpose of these long narrow boxes, or sand traps, is to permit the heavier particles of impurities in the washed stock to settle out and collect on the rough surface of the dryer felt, or behind the dams. The efficiency of the sand traps is dependent on the dilution of the stock, the rate of flow over the course, and the length of the course. The depth of the stock is about 8 inches, the slope of the course is about $\frac{1}{2}$ inch per foot of length, and the longer the length of the course the more impurities will settle down.

The impurities found in these traps are mostly pins and clips, such as are attached to letters, staples and fasteners from book backs, rubber bands, bits of rags and strings, sand, and heavy pieces of grit. A film of fine particles of iron rust is found to be covering most of the dryer felt bottom.

128. Furnishing the Beaters.—From the sand trap, the stock may go back to the chest, or through the screen and to the beater or wet machine. When the beaters are ready to be furnished, the gate to the screens is opened, and the stock from the sand trap flows onto the screen. Here it is diluted with water, to separate fibers from impurities, and to enable the stock to be screened without clogging the slots and flooding the entire screening

surface. If the latter should occur, an overflow is arranged to take care of the stock, and this overflow returns the stock to the storage tanks.

In most of these single screens, three (3) plates are cut 0.010 inch and the other three 0.016 inch, or thereabouts. The density of the diluted stock as it is furnished to the beater is equivalent to 1.27% furnish; this means that 1 pound of dry stock is diluted with 9.44 gallons of water, since $1 \div (9.44 \times 8\frac{1}{3}) = 0.0127 = 1.27\%$. To furnish 600 pounds of dry stock at this dilution, the washing cylinders in the beaters must remove $600 \times 9.44 = 5664$ gallons of water, which requires from 45 minutes to 1 hour.

Since 99% of the fine dirt particles have a diameter smaller than 0.016 inch, they have free passage through this size of openings in the screen. The paper made from this screened stock is sprinkled with fine dirt particles, and the quality of the product is thereby lowered.

129. Effect of Poor Screening.—By far the largest percentage of the materials retained on the screens consists of small bits and particles of broke or paper, which have not been completely de-fibered in the washing engine. The amount of this material in the screenings has startled many mill superintendents; but, instead of remedying the trouble, they have side-stepped it by increasing the size of the screen cuts, in some instances up to 0.028 inch. This, of course, cuts down the amount of screened un-de-fibered stock somewhat. An attempt is made to clear or finish the de-fibering of this stock in the beater and, later, by refining it shorter in the Jordan engine. This method may work part of the time; but, occasionally, the increased production of the paper machine calls for more stock, in which case, the beaters are crowded and cannot condition the stock in the same degree. Then, too, when the stock is run long, that is, when a good strong-fibered sheet is required, very little beating is necessary, except to clear the sulphite or soda pulps used, and the Jordan engine action is reduced almost to a bare clearing of the stock. The result is that the finished sheet is sprinkled with these particles of un-de-fibered stock of varying size. At times, they are so much in evidence that they are the cause of the sheet's breaking down at the wet presses, and offer untold difficulties in carrying the sheet over to the calenders, besides being a means of

carrying ink particles into the paper. The reason for this breaking down is explained by the fact that the particles of broke have no felting power, and whenever they are present, they produce a weakened spot in the sheet. On going through the calenders, these are made transparent, and they stand out quite distinctly in the finished sheet. This defect in the finished paper, especially in coated paper, results in sheets of lower quality, or seconds.

QUESTIONS

(1) What factors influence the rate and completeness of washing old-paper stock?

(2) About how much bleaching powder is required to bleach, in pulp form, 100 lb. of dry papers?

(3) What is your opinion of the suggestion to use a wet machine in the handling of cooked waste-paper stock?

(4) What kind of equipment is used in screening waste-paper stock? Explain the importance of this operation.

TREATMENT OF WASTE PAPERS

EXAMINATION QUESTIONS

(1) Mention some reasons for the extensive use of waste papers.

(2) (*a*) What chemical action takes place in the removal of printing ink? (*b*) What kind of chemical is used?

(3) What are the four principal classes of waste papers?

(4) Name the principal operations in treating waste papers for paper making.

(5) Describe, with sketch, one type of waste-paper duster, and tell how it works.

(6) What becomes of the discards from the sorting room?

(7) Explain the term dry cook and the result of a dry cook.

(8) If you were planning a mill, would you consider the recovery of soda-ash liquor an important factor? Give reasons for your answer.

(9) (*a*) What are the three principal factors in cooking? (*b*) how does a change in one affect the other two?

(10) What influence would the cost of power exert in connection with the selection of the cooking-engine process?

(11) (*a*) If the consistency of a 900-lb. batch of papers being cooked is 5%, what is the total weight of the charge? (*b*) If 4% soda ash on the weight of the dry paper is added, what is the total weight of the charge?

Ans. $\begin{cases} (a) \text{ 18,000 lb.} \\ (b) \text{ 18,036 lb.} \end{cases}$

(12) Taking 1 B.t.u. as the heat required to raise the temperature of 1 lb. of water 1°F., and assuming paper and soda ash to have the same specific heat as water, how many heat units will be required to raise the temperature of the batch in the last question from 45° to 175°F.? Ans. 2,344,680 B.t.u.

(13) What test shows when bleach residues have been washed out of the stock?

(14) (*a*) Give maximum, minimum, and average losses in washing old-paper stock. (*b*) Mention some sources of these losses.

(15) (*a*) Which method of cooking old waste papers is most popular? (*b*) Which method do you consider best? Give reasons.

SECTION 3

BEATING AND REFINING

By Arthur B. Green, A.B., S.B.

with Bibliography

By C. J. West, Ph.D.

INTRODUCTION

1. The Preparation and Supply of Stock for the Paper Machine. The two operations of **beating and refining** also accomplish the necessary mixing of the various materials that are to go into the final paper, and also the necessary reduction of the pulps, or fibrous materials, to such a state that they will form themselves into a sheet of the desired characteristics. As for the many classes of pulps, the sources from which they are derived, the processes by which they are extracted from nature, and the processes by which they are purified and whitened, these have already been dealt with in preceding sections. These processes fit the different pulps in various ways for the operation of beating. They may or may not be carried on in the same works, or under the same management, as the beating and refining themselves; but wherever beating and refining are carried on, they represent the first step in the actual making of paper, and are always included in the same works, and under the same management, as the paper machines, which transform pulp into paper.

Beating and refining are different processes. Where they are both carried on, however, they are for the same purpose, and constitute two successive steps in the preparation of the stock

Note.—Special acknowledgement is hereby made to Frederick A. Curtis, of the United States Bureau of Standards, for valuable assistance in the revision and arrangement of the manuscript and in the preparation of the photo-micrographs.

for the paper machine. Refining is not always done; but, with very few exceptions indeed, there is always something in the nature of beating as the first step in making paper from pulp. In some grades of paper, the amount of beating required is so slight that the process has degenerated from a highly skilled operation to hardly more than proportioning and mixing, carried out almost automatically. Newsprint is one of these grades, and great tonnage of paper is made every day with no more beating than this. Nevertheless, in higher, more expensive, grades of paper, it is the beating that largely determines the quality and value of the final product.

2. Beating Defined.—**Beating** is a general term for the mechanical treatment given to paper-making materials suspended in water, to mix them and to prepare them for forming on the paper machine a paper of the desired character. **Refining** is a further mechanical treatment, which usually follows the beating or mixing, to complete the preparation of the materials.

The beater and the refiner are different pieces of equipment. There is usually more than one beater for one paper machine, the several beaters being furnished and dumped in rotation, all discharging to a common chest on the floor below. Thus beating is done in batches, and comes under the class of processes known as "batch" processes. The chest on the lower floor serves as a reservoir from which the beaten stock is pumped up to the refiner in one continuous stream, and thus it passes continuously through the refiner. Refining falls under the class known as "continuous" processes. There may be one refiner for one paper machine, or there may be several; in the latter case, they may work in parallel for capacity, or in series for maximum action on the fiber.

It is at the beater that the materials which are to impart to the final paper its color, opacity, sizing, etc. are added to the fibrous pulps. These materials are not pulps; they are non-fibrous. Their action and their effect is partly physical and partly chemical.

3. History of Beating.—Not all of the facts are known that would be necessary to fix the exact time and place of the first use of beating. The very early papers made in China were fashioned from fibers of the inner bark of certain trees; and the nature of these fibers allowed of enmeshing them into a sheet

without beating, so long as the work was done by hand and the uses of paper were confined to such qualities as could be produced in this way. In the eighth century, the art spread from the Chinese to the Arabs, then from the Arabs to the Greeks and Moors, and reached Europe in the thirteenth century, by which time, rags had become so general as raw material for paper as to make it certain that some beating must have been done before the fibers were ready for the hand mold.

The early process for reducing cotton rags to pulp consisted first of rotting, next washing in open streams in bags, and finally pounding, either with mortar and pestle, or on stone surfaces with hard wooden implements. The pounding was hand labor; but before the eighteenth century, machinery was devised for doing the pounding; that is, heavy wooden stampers were fitted to a row of upright cylinders, or pans, made of wood or stone, and by means of trippers attached to a shaft driven by a water-wheel these stampers were raised and allowed to fall. This was known as the stamping mill.

These stampers were divided into three groups: The first group were shod with heavy iron teeth or nails, to tear the rags; the second group were shod with finer teeth to draw out the fibers; and the third group were of hard wood, weighted but not shod, and served to bruise the fibers. Fresh running water in the first two groups of pans washed the rags through holes in the bottom, covered with fine hair-cloth. It is said that this process of beating took about 32 hours, and that a mill with six pans could produce about 500 pounds a week. Fibers treated by these early processes went into the paper very much greater in length than is the case with any grades of modern paper; and the sheets that have been preserved from early times show remarkable strength.

4. Invention of the Hollander.—About the middle of the eighteenth century one of the great steps was taken in the advancement of the paper-making art when the Hollander beater was developed in Holland to replace the stamping mill. It was claimed that two beaters could be run by the power required for one set of stamps. Instead of the row of cylinders or pans, there was an open tub, roughly oblong, with ends rounded, and with a partition in the center, built parallel with the straight sides, allowing continuous flow of the pulp along one side, around the

end, along the other side, and around the other end. On one side of the partition, a roll was mounted on a heavy spindle, which extended across the tub at right angles with the long side. Under the roll was built a suitable bed-plate; and both roll and bed-plate were fitted with bars of metal. Near the roll, on the side turning upward, was built a back-fall, over which the roll would throw the pulp, and over the roll was a hood to confine the splash. Thus, as the roll was turned rapidly in close bearing upon the bed-plate, the pulp was propelled around the open tub, and passed repeatedly under the roll. The Hollander is the type of beater in common use today; and in principle it has not been changed since its invention, nearly two hundred years ago.

BEATER CONSTRUCTION AND OPERATION

TYPES OF BEATERS

5. General Considerations.—Although beating, as a necessary means of preparation of the stuff,[1] has been in use for three centuries or more, nevertheless it is not yet possible to state accurately what the beater accomplishes. Brushing, cutting, bruising, brooming, hydrating, attrition, are among the terms used to describe what happens to the fiber in the course of beater treatment, but these are general terms, and it is impossible to say how many of them apply to the beating of any particular kind of stuff, or in what proportions these various actions take place. This phase of the subject will have further treatment in later parts of this Section, under the heading Theory of Beating; but in considering the various designs of beating equipment now to be described, it should be borne in mind that none of them can be said to be based on accurate knowledge of the beating action.

The different types of beaters are described approximately in the order of the extent to which they are used. The first, the Holländer, now generally written Hollander, is by far the most prevalent.

[1] **Stuff** is the name given to fibrous paper-making materials after mixture with whatever non-fibrous substances are used and after beating and refining, ready for the paper machine. These materials are in suspension in water. The milky mixture flowing out on the paper machine is also called stuff, but in this book it will be called **stock**. It has been modified from the beaten and refined state only by dilution with water and with back-water from the machine. Pulps ready to furnish to the beater, particularly in fine paper mills, are called **half-stuff.**

THE HOLLANDER

6. The Hollander Tub.—The **tub** of the Hollander consists of an open vessel, built usually of wood or cast iron, the wooden construction being shown at *A*, Fig. 1. The rounded ends of the tub, in conjunction with the central partition *B*, called the

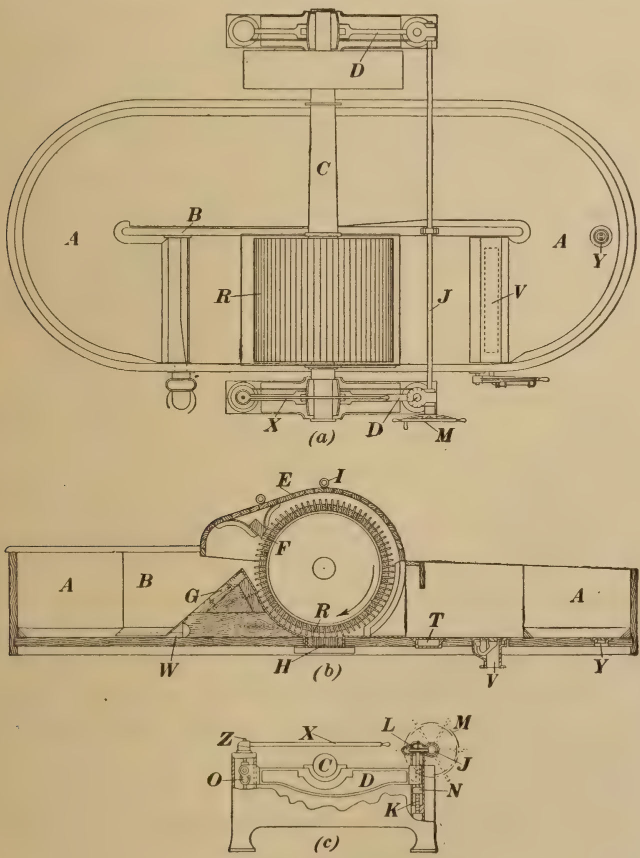


FIG. 1.

midfeather, or *midboard,* form the channel through which the stock travels in continuous circuit. In later types, the tub has been made of concrete, though this has been used more often where the design of the tub is more complex, that is, in other designs of beaters. The cast-iron tub is best adapted where heat is used in the beater to assist in disintegrating old-paper stock, as in board mills. In mills making fine papers, where color and

cleanliness are prime requirements, beater tubs are lined with sheet copper and beater bars and bed-plate knives are made of a non-corroding metal such as bronze. A Hollander beater measuring approximately 20 feet long and 9 feet wide, with sides about 3 feet 6 inches high, will hold approximately 1350 pounds of air-dry stock at a consistency of about 5%.

An integral part of the beater tub is the **back-fall** G, shaped on one side to conform to the curve of the beater roll, and having on the other side a steep slope. The roll throws the stuff over its crest, thus forming a head, so that the force of gravity causes the stuff to travel away from the roll, around the tub, and thus back to the roll again. This travel is called *circulation*, and stuff circulating in the beater tub is said to *turn*. Due partly to the use of short-fibered stocks in recent years, the design of the tub and back-fall is receiving considerable study, and many modifications are now offered, without departing from the Hollander type, to secure more rapid circulation and beating.

7. In some beaters, as an aid in dumping the stock, water may be introduced at the base of the back-fall, as shown at W. For certain kinds of stock, especially with rag half-stuff, the beater is equipped with a narrow metal box T, Fig. 1 (b), set in the floor and covered with a perforated plate. This acts as a trap for heavy particles of metal, dirt, or sand, and is called a **sand trap.** It is cleaned through a small opening to the sewer or by hand. Valve Y is a sewer connection for cleaning out the tub, and is V a valve for emptying, or dumping, the beaten stock to the chest. In most cases, these valves consist essentially of a heavy metal plate or disk, fitting into the opening with a ground joint. In some recent designs, the dumping valve may extend from the front side to the midfeather and be so designed that, when the cover is raised, it acts as a baffle to deflect the stock to the opening.

In Fig. 1 (b), it will be noticed that the bottom of the tub is flat, and that there is only a small fillet around the bottom of the tub and midfeather where it is joined to the sides of the tub. An increased speed of circulation and a higher concentration or density (consistency) of stock are rendered possible by raising the bottom of the back-fall at W higher than the bottom of the tub at Y or T, thus permitting a gentle slope for the stock. Lodging of inert or dead stock in the corners can be avoided by having

the bottom of the tub U shaped, as can be readily done with concrete construction.

8. Beater Roll and Bars.—A heavy spindle C is mounted across the tub at right angles to the midfeather, and is supported in bearings at its ends, the bearings resting in lighter bars D. To this spindle is firmly attached the beater roll R, usually called the **roll.** The spindle and roll are revolved by means of a belt or chain drive from a constant speed shaft or motor to a large pulley on the back side of the tub. This pulley may be either inside or outside the back-side lighter bar.

9. The typical beater roll is built on three or more cast-iron spiders A, Fig. 2, which are keyed to the roll spindle B. The

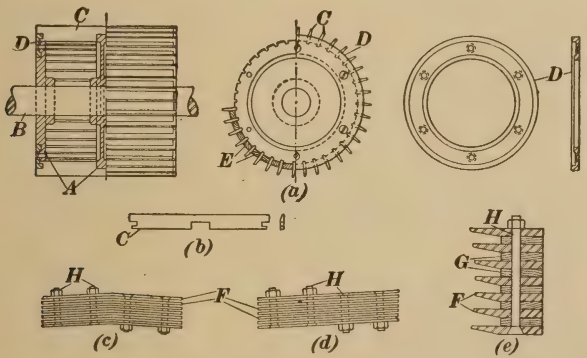


Fig. 2.

spiders are slotted to receive the **fly bars** C. These bars are themselves slotted at both ends, as shown in detail at (b), for the hoop or band D by which the bars are usually held in place and kept from flying off at a tangent. The bars may be evenly spaced or set in clusters, the arrangement and number varying with the kind of stock to be beaten and the kind of paper to be made. Wooden blocks E, cut slightly wedge shape, and called *filling*, are driven tightly between the bars. This filling is made from dry, well-seasoned, hard wood; and the water in the tub produces a swelling of the wood, which tends to hold the bars fast and prevent vibration. There are, however, several methods of fastening the bars C to the spiders A. In one case, the bar is dropped into a notch in each spider, and is fastened in place by drilling a hole in the bar over a pin or lug in the side of the notch, the bar being firmly held by pouring in a low melting alloy, or by

screwing down a wedge. In other cases, the bars are held in place by a circular plate or hoop *D*, which is firmly bolted to the outside spiders, and by a driven fit in the slots of the spiders.

The beater roll *R*, Fig. 1, is so designed that its width (face) nearly fills the space between one side of the beater tub and the midfeather. It may weigh, together with the spindle and pulley, from 3000 to 6000 pounds and may be revolved at a peripheral speed of from 1500 to 2500 feet per minute. The width and diameter of the roll depend upon the dimensions of the beater.

10. In most cases, the beater-roll bars are made of metal; steel is in most common use, though bronze, manganese bronze, phosphor bronze and manganese steel are also used. A new design provides a cylindrical shell with the bars on the outside and spiders inside, all cast in one piece, and the bar edges turned true. Since different kinds of stock need different beating treatment, it is necessary to consider the quality of the bars for the particular stock to be beaten. For certain papers where the stock has to be beaten very "wet," such as glassine, or where the paper must be free from metal particles, such as sensitizing paper and condenser paper, a stone roll is of value, because iron causes rust spots, discoloration of tints, etc. This latter type of roll is usually made of basalt lava or a mixture of concrete and quartz, and may be built up by using narrow blocks that are held to the spiders by pins or bolts. Blocks of porous cast iron may be employed in the same way. A roll may be cut out of a block of basalt lava or built up with concrete and flint on an old roll, by removing some of the bars and using the others for a bond.

11. In order to prevent loss of the stock that is carried around between the bars of the roll, a covering *E*, called a **hood** or **curb,** is placed over the roll. This, in part, conforms to the shape of the roll and extends back and down the sides and is firmly bolted to the sides of the beater tub. To facilitate the circulation of the stock and to prevent it from being carried over the top of the roll, a baffle *F* is attached to the curb to deflect the stock over the backfall. The design of the curb and baffle is of great importance. A recent design aims to avoid "churning" by introducing air through a perforated bed-plate.

12. The Bed-Plate.—Directly beneath the roll is the **bed-plate** *H*, Fig. 1, frequently called the **plate**; it is set in a chair or box by means of wooden wedges accurately parallel to the axis

of the roll. The bed-plate, Fig. 2 (*c*) and (*d*), is made up of strips of metal or bars *F*, set on edge, spaced with wood filling *G*, and firmly bolted together at *H*. This is shown in large detail at (*e*). These plates may be elbow plates, as shown at (*c*), or may be straight, as shown at (*d*), and set at a slight angle to the axis of the roll, or may take one of numerous other forms. The plate and plate box, or *chair*, are so designed that the plate may be removed through an opening in the side of the beater when necessary, by removing a bolted cover plate.

13. The Roll-Adjusting Mechanism.—In the operation of the beater, the only adjustment made after beating begins is the raising or lowering of the roll; the mechanism for accomplishing this is shown in detail at (*c*), Fig. 1. The lighter-bar *D* is pivoted at one end at *O*; the other end rests on a nut *N* that runs on a vertical threaded rod *K*, between guides in the lighter stand, which keep the nut from turning. At the upper end of the rod *K* is a worm gear *L*; this engages with a worm on the shaft *J*, which extends across both lighter stands and is turned by means of the wheel *M*. In this manner, a very minute vertical adjustment is given to the end of the lighter-bar *D*. Since the bearing that supports the spindle *C* is at the middle of the lighter-bar, the spindle receives just one-half of this adjustment. One turn of the hand wheel *M* raises or lowers the beater roll approximately one one-hundreth of an inch. Bevel gears may be used in place of the worm gear and worm. At *Z* is a spiral cam. In case of an emergency, a pull on handle *X* will raise the roll one-half inch or more.

In some makes, the bed-plate is pushed against the roll. More than one bed-plate may be used.

SPECIAL TYPES OF BEATERS

14. Defects of the Hollander.—There are a number of grounds for criticising the modern Hollander beater, among which are: large power consumption; low beating capacity; insufficient mixing of the various ingredients of the furnish; large floor space required; and lack of close control over the beating operation. During the past fifty years, there have been numerous attempts to improve on the design of the Hollander. These attempts have resulted in a large variety of engines of various kinds. Some of the more important types will now be described in detail.

15. The Horne Beater.—One of the functions of a beater is that of *mixing*, and the ordinary Hollander beater was found to be faulty in this respect. By referring again to Fig. 1, it may be inferred from the plan view (a) that portions of the stuff flowing next to the midfeather will remain there indefinitely, for there is nothing to throw them to the outside; and this will be found to be the case. The Horne beater (patented in August, 1886) was designed to overcome this deficiency and is illustrated in Fig. 3. Instead of running with its top above the surface of

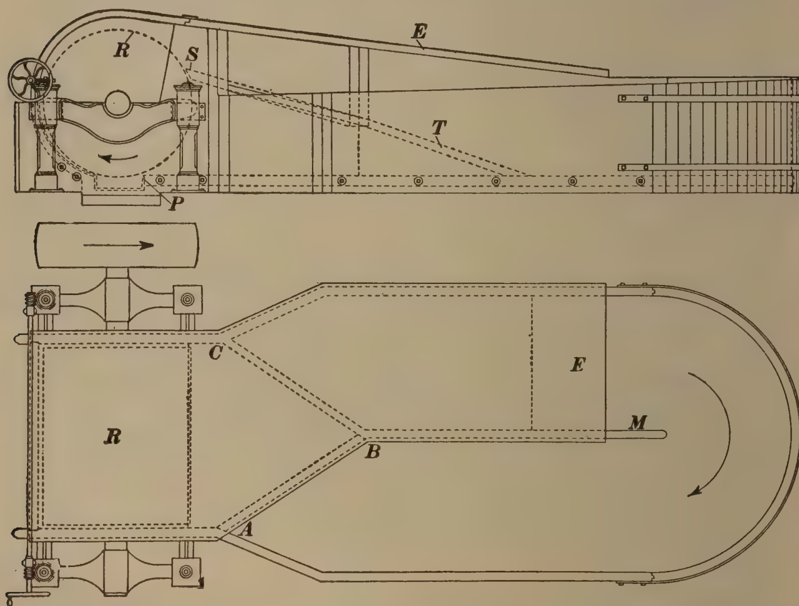


Fig. 3.

the stock, as in the Hollander, the beater roll R is submerged, and instead of being placed at the center of the tub, it is located at one end. The midfeather M, as it approaches the roll, is turned across the tub at BC, where the top joins the back-fall T, which ends in a shoe S that acts as a *doctor*, to deflect the stock from the roll. Thus the stock is carried between the roll R and the bed-plate P, thence around and over the roll, where it is deflected by the shoe S and is sent back on the other side of the midfeather and under the back-fall at AB, to the roll again. The back-fall creates the head that forces the stock around the tub. As the stock nears the roll, the channel through which it is

traveling becomes wider and shallower, finally reaching a width equal to that of the roll. Those portions of the stock, therefore, which approach the roll from a position next to the midfeather, actually return from the roll in a position next to the outside of the tub. This action may be readily observed in a mill when the beaterman puts in the colors.

As the head of stuff over the shoe may, under some conditions, be considerable, the return side of the tub is covered with stout plank *E*, which extends nearly to the end of the midfeather, where the sectional area of the channel again becomes normal. The roll is carried and adjusted by the same type of mechanism that is used with the Hollander.

16. The Umpherston Beater.—Another deficiency of the Hollander beater is the large floor area required to operate

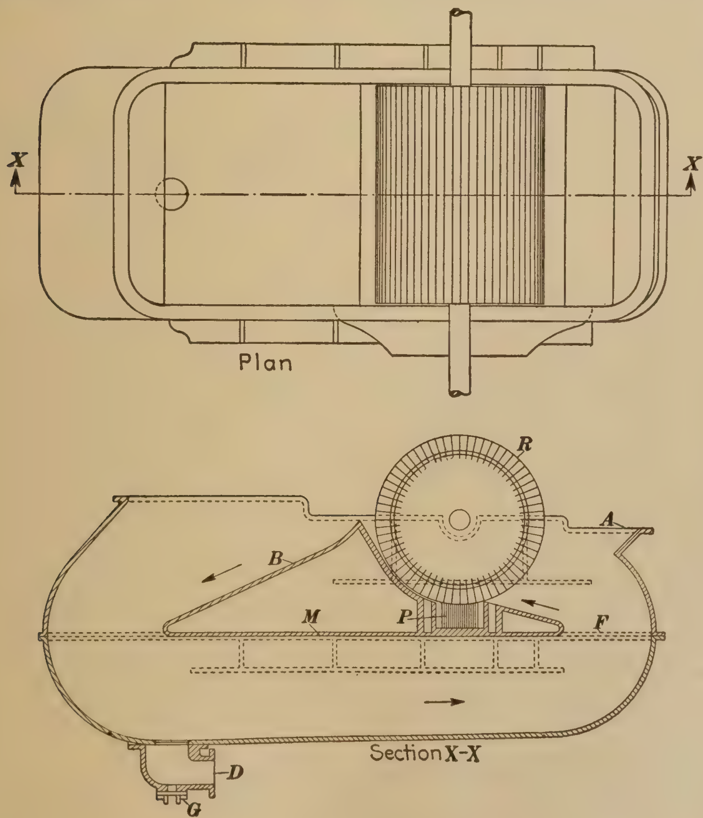


FIG. 4.

it. There have been many attempts to improve upon the Hollander in this respect, notably in the Taylor and the Umpherston beaters. The Taylor is rarely found in use now, but the Umpherston is on the market and is not uncommon. In both of these types, it is sought to economize floor space by circulating the stock, not in a horizontal path but in a vertical one, passing downward through the floor and up again on the return.

The Umpherston beater is illustrated in Fig. 4. The tub, made of cast iron, is in the form of a shell, in two parts, set into the floor up to the level of the flanges *F*, where the two halves of the tub are fastened together. The midfeather *M* and the back-fall *B* are one piece, set in a horizontal position; and in the same casting is carried the chair for the bed-plate *P*. The stock is furnished at *A* and dumped through the spout at *D*. The cast-iron fitting through which the dumping is effected is provided with a packing gland *G*, through which runs a vertical spindle. The spindle operates a cap, or plug, fastened to its upper end, and raises the cap, to allow the stock to drop; it is also connected by a lever to a handle above the floor, which operates the valve. The roll *R* extends across the full width of the beater.

17. The bed-plate is set in a cast-iron chair, or box, as in other types of beaters, and is driven to position between wedges; it is removed for repairs, or raised, through a cover plate on the side of the tub, just above the juncture of the two halves of the tub casting. The lighter mechanism, unlike the Hollander, does not have a lever but consists of an L- or boot-shaped support with the roll-bearing box resting on the tip of the horizontal part. The vertical part may end in the form of a screw running in a composition-metal nut at the top. This nut is geared to a hand-wheel shaft, extending across the tub, by means of which both ends of the roll spindle are adjusted exactly and together, similar to the hand-wheel mechanism of the Hollander. This mechanism is housed in a casting, also L-shaped, which rests on a bracket cast on the side of the tub; it is provided with a locknut adjustment, by means of which the roll may be alined horizontally.

18. The Miller Duplex Beater.—Investigators have endeavored many times to increase the amount of roll action possible during one circuit of the stock around the tub. It is urged that more

cutting action in the same capacity of tub will result in a more efficient beater.

A recent application of the foregoing reasoning is embodied in the Miller duplex beater, which is shown in Fig. 5. Its operation is similar in principle to that of the Umpherston, except that a second bed-plate is placed above the roll. The lower bed-plate P_1 is of course, fixed in position, while the lighter mechanism, in addition to carrying the roll itself, also carries the upper plate P_2. The adjusting device that raises and lowers the roll is so designed as to move the upper plate P_2 exactly twice as far; thus the

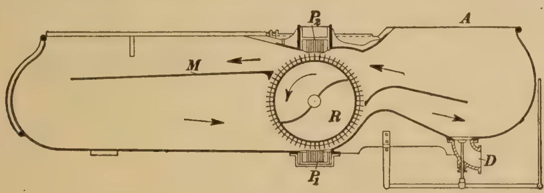


FIG. 5.

distance between the roll and the lower plate is always equal to the distance between the roll and the upper plate. Springs are used to take up any shock on the upper plate in case of hard objects passing through. The dumping valve D is similar to that of the Umpherston.

19. The Marx Beater.—The Marx beater, shown in Fig. 6, is in line with the effort to obtain more roll action for the same capacity of tub. Here, however, there are two complete sets of roll and bed-plate, each with its own lighter equipment; and to accommodate them, the tub is designed in the form of a circuit channel, the midfeather being changed into an enclosure for the inboard lighter sets and pulleys. An advantage derived from this design is that one set of roll and bed-plate can be made of one type and the other set of another type, thus producing two separate kinds of action on the stock in a single circuit around the tub. In Fig. 6, roll R_1 is a stone roll, while roll R_2 has metal bars.

The lighter equipment, shown in detail at (*b*), Fig. 6, embodies a refinement in the adjustment of the roll, which is effected by a lever A and counterpoise W. By sliding the weight W outward on the lever, more of the weight of the roll can be counterbalanced, thus leaving less of its weight to act on the stock. It is to

be noted that in duplicating the roll and bed-plate, it is also necessary to duplicate the dumping outlet *O*, because there are two low places in the bottom of the tub, one in front of each roll.

The roll, if made of stone, may be turned from a solid block and scored to form bars; or wedges may be set in special disks

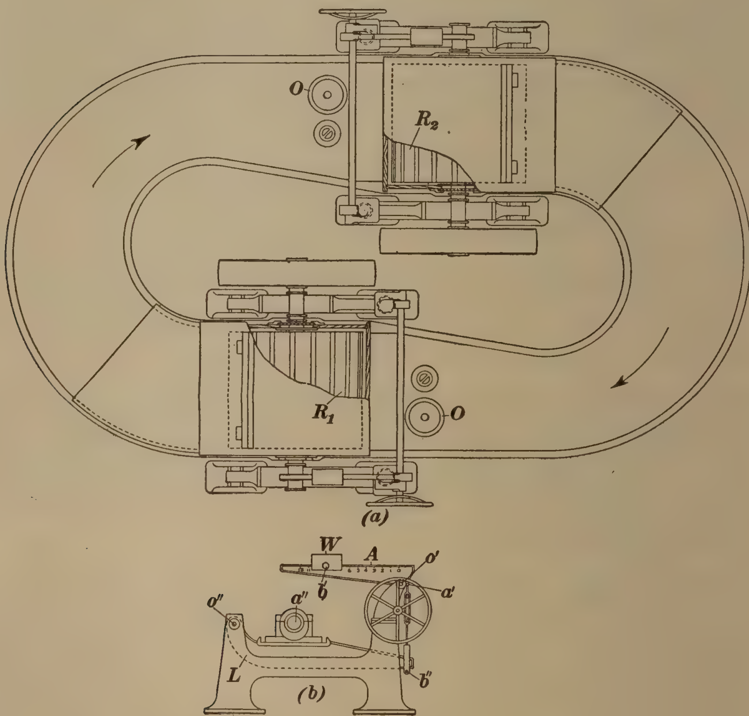


Fig. 6.

or headers. The selection of the stone is very important. Basalt lava is often best; it has small cavities, whose edges cut and do not crumble.

20. The Rabus Beater.—The Rabus beater, shown in Fig. 7, is similar in arrangement to the Horne beater. The tub, however, is modified into the form of a closed circuit, with open midfeather, in the effort to obtain more rapid circulation of the stock with the same expenditure of power. The channel is deeper and is shaped to facilitate the flow of stock and prevent lodging.

Note that the stock flows in a direction opposite to that in the Horne beater, Fig. 3.

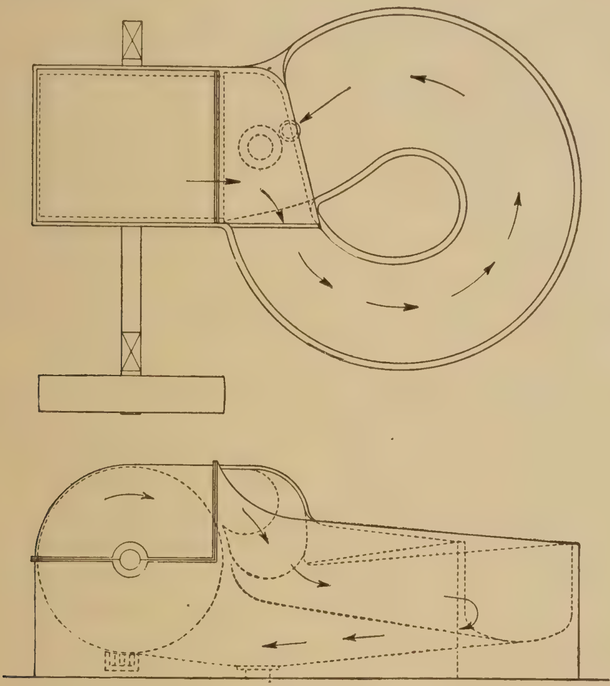


FIG. 7.

21. The Niagara Beater.—A very recent design, which has met with great success on many grades of paper in reducing the power

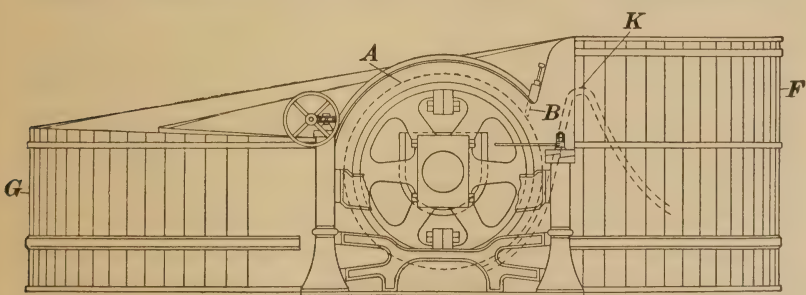


FIG. 8.

expenditure in beating, the time required, and the floor space, as compared with the Hollander, is the Niagara beater, shown in Fig. 8. Great attention has here been paid to the design of the

channels through which the stock must circulate. A U-shaped bottom and a very high back-fall are employed; and there is a marked difference between the width of the channel at the front side and at the roll side of the tub. Although the roll is not submerged, it has, nevertheless, the effect of being submerged, by reason of the great height to which it throws the stock over the back-fall *K*. The marked reduction in time required for beating with this beater is attributed to the improved circulation of the stock, which not only allows the roll to treat the same portion of the stock more frequently but also renders a considerable portion of the power used in circulation available for mechanical work by the roll and bed-plate on the stock; and this is accomplished with an unusually high consistency of stock.

22. The Emerson Beater.—Another method of obviating the tendency of the stock that lies next to the midfeather to remain there is the device employed in the Emerson beater. The midfeather is made in two parts, exactly alike, set parallel to each other in one tub, with space enough between them to place the roll. The roll is mounted on a spindle that spans the entire tub, as in the case of the Hollander, with the lighter equipment standing outside the tub. Thus, the stock passes under the roll in this central channel, over the back-fall; it is divided at the rear end of the two midfeathers, one half passing to the right and the other half to the left, in two separate channels, to the front of the engine, where the two streams reunite in the central channel and again approach the roll. In the Emerson beater, the tub is more nearly oblong in plan.

23. The Stobie Beater.—Probably the modern development of short-fibered chemical and mechanical wood pulps has brought forth no more bold departure from precedent, in the matter of design, than the Stobie beater. This apparatus could not be employed on long-fibered stocks, but it applies admirably to such materials as sulphite, kraft, soda, and groundwood fibers.

An open-tub beater is used as a container in which to mix the ingredients of the furnish and to break up the laps and dry broke[1] that may be used. The mass is then dropped into a chest, which

[1] **Broke** is paper that has been discarded anywhere in the process of manufacture. *Wet broke* is paper taken off a wet press of a paper machine; *dry broke* is made when paper is spoiled in going over the dryers or through the calenders, trimmed off in the rewinding of rolls, or trimmed from sheets being prepared for shipping.

is provided with a good agitator. Drawing from the bottom of this chest is a three-stage centrifugal pump, which is capable of delivering the stock above the top of the chest to three or four fire nozzles, arranged in a battery and shooting horizontally, at a pressure of about 75 pounds per square inch. Before them is arranged a plate, the surface of which is serrated (something like the tread of an iron stair), and which is set at an angle that will deflect the stock downward again into the chest. In this manner, the stock is circulated from chest to pump, to nozzles, to plate and back to chest for a given period of time. It is then delivered to the paper-machine chest without any further refining. Stock at a consistency of 2.5% is circulated for a period of 20 minutes, the nozzles acting under a pressure of 75 pounds per square inch, the serrated plate being set at an angle of about 45 degrees. These conditions are roughly the average for a hard all-sulphite paper.

In power requirements, the pump is about equivalent to a large Jordan engine; and there is also to be added the power required to drive the breaking engine, in which, however, it is not always necessary to set down the roll. On rough computation, the Stobie beater would require about 120 h.p.-hours per ton of paper on a grade that would require about 370 h.p.-hours per ton of paper when beaten according to the usual methods; this represents a power saving of about 67%.

Besides the saving in power, the Stobie process affords the opportunity of gaining close control. Once the consistency has been governed, there are only four other variable factors: the pressure; the character of the plates; the angle at which the plates are set; and the length of time of beating. The character of the plate and the angle at which it is set may be fixed mechanically, and a recording pressure gauge will show both the pressure and the time. If, then, the management specifies what nozzle pressure to use and for what length of time the process must run in each furnish of stock, there is practically absolute control, with consequent uniformity of results, the only remaining condition that may vary being the characteristics of the raw stock.

24. Beating with Rods.—A recent development in the preparation of stock for paper machines is beating with rods. By the use of this device, it has been possible to reduce the horsepower required in beating 50 to 70 per cent and, at the same

time, avoid the cutting of the fibers that always occurs when ordinary beaters are used. It is possible to obtain separation, fibrillation, and hydration under close control, and usually with better results than is commonly obtained by other means. Not only is this an effective arrangement for beating, but it is also equally adaptable to the pulping of screenings, knots, softened wood chips, cereal straw, flax straw, etc. The device has recently been patented[1] and is receiving much attention in the paper industry.

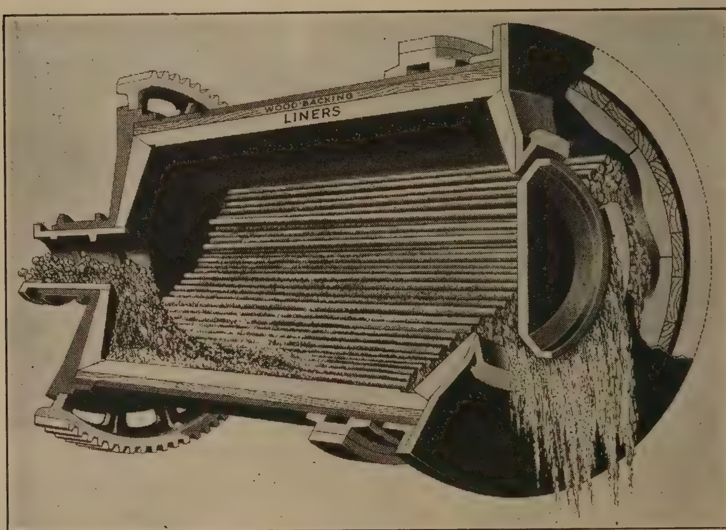


Fig. 9.

When beating with rods, it has been found feasible to utilize the rod mill commonly used in the mining industry for grinding. There are two general types of rod mills: One is the *displacement type*, which has an outlet of substantially the same diameter as the inlet; the other type is the *enlarged-outlet*, or *positive-flow*, *type*. In the former, the stock entering the mill displaces a volume equal to that being forced out; the level of the stock in the mill is as high as the outlet, and a large pool forms at the bottom of the rod pile. In the other type, the pulp line in the mill is low, and with the inlet higher than the outlet, there is a positive flow.

Both types consist of horizontal cylinders, half filled with steel rods, with inlet at one end and outlet at the other end.

[1] U. S. Patent No. 1,654,624.

Often the trunnions on which the mill revolves are hollow and serve as inlet and outlet. The mill revolves on its horizontal, longitudinal axis and may be mounted on rollers as well as trunnions if it be desired to reduce friction and save power. One design of mill has truncated conical ends, which serve to keep the rods in proper position and also provide internal pockets for facilitating the entrance of the stock between the rods and its emergence therefrom. Fig. 9 shows a mill that combines many of the features mentioned above. It is supported by the

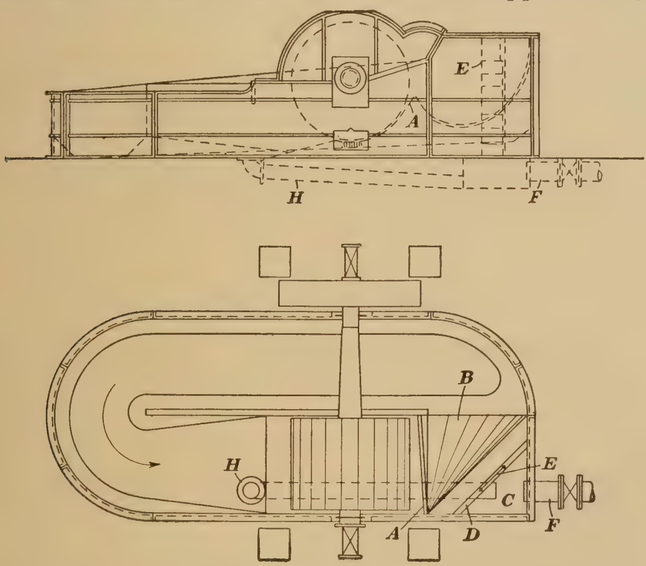


Fig. 9a.

trunnion at the left and the ring near the right, which rests on rollers.

A mill 6 feet in diameter and 12 feet in length, containing 42,000 pounds of steel rods and rotated at 14 r.p.m., requires approximately 90 h.p. to operate it. The diameter of the rods used in the experimental work ranged from $1\frac{1}{2}$ to 3 inches. The rods are made of electrolytic steel, so as to be as nearly rustless as possible and thus avoid staining the pulp. The choice of steel or rubber lining with steel or rubber-covered rods should depend on the stock to be beaten.

Another very recently designed rod mill has conical ends and larger trunnions. It is claimed that this make keeps the rods alined, with minimum wear on the ends of the mill. Also, that

the pulp level can be changed by opening one or more of the variously disposed discharge ports in the cone at the discharge end. This form also allows additional free space at the ends.

24A. A Broke Beater.—A beater designed especially for the continuous conditioning of broke is shown in Fig. 9*a*. It has a peculiarly shaped concrete bottom and a relatively low back-fall *A*. The bottom behind the back-fall slopes up from the curved bottom into a flat plate at an angle of about 45 degrees with the side of the beater. This part of the bottom is perforated and acts as an extractor plate *B*, through which the de-fibered stock passes to the sump *C*, which is formed by making the side and end of the beater meet in a square corner, which is shut off by a dam *D*. A regulating weir *E* controls the rate at which the defibered stock is extracted from the beater and fed to the pumps through the pipe *F*. There is a washout valve and pipe at *H*.

CARE OF BEATERS

25. Necessity for Exercising Care.—The very simplicity of the design and construction of most types of beaters tends to promote laxity in caring for them. This is particularly true in mills making coarse boards or saturating felts; and it applies also to mills using waste paper and cheap pulps, where the beater acts largely as a mixing vat and the roll is not lowered to any extent. But it is in mills making fine papers, where the beaters are carefully handled, that particular attention must be paid to the condition of the fly-bars and bed-plate, the adjustment of the deflector in the curb, cleanliness, power consumption, and the condition of the roll-adjusting mechanism and bearings.

26. Grinding of the Roll Bars.—During beating, the fly-bars of the roll and the knives of the bed-plate become worn, and they must be replaced from time to time. It has been shown that the bars may easily be removed from the roll; also that the bed-plate may be taken from the beater by removing a plate on the side of the tube, taking out the wedges holding the chair or box, and sliding the plate out. It is sometimes possible to continue to use a worn roll and plate by chipping out some of the wood between the bars and thus have pockets deep enough between them to produce the necessary circulation.

27. After the roll has been filled, it is necessary to grind it to a true fit with its bed-plate; and the grinding must be done in such manner as to insure that all bars come into contact throughout their entire length. The old way of doing this, which is still to be preferred where the finest beating is to be done, is to place in the tub, in front of and behind the roll, suitable dams. The space between the roll and the dam is filled with fine, sharp sand, and the roll is turned against the bed-plate in this fine sand until the sound it makes and an inspection of the bars indicate a perfect fit. During this operation, enough water must be added periodically to prevent the development of too much heat.

A quicker method, but not so satisfactory for fine beating, is to remove the roll, mount it in a lathe, and bring the bars to their proper form by means of a grinding wheel. The bed-plate is then placed under a grinding wheel, which swings over a radius equal to that of the roll with which it is to run. In practice, this method is available only to the larger mills, because in smaller mills it is costly to remove the roll from the beater for refilling. It is generally desirable to grind a new roll, also, except where it is to be used for coarse boards or felts.

In addition to the wearing down of the bars during beating, there is a change in the degree of sharpness or dullness of the bars, which is a very important factor in many classes of paper. Blotting paper requires sharp bars, whereas glassine and high-grade bond and ledger papers require dull edges on the bars.

28. Cleanliness.—In mills making white or colored papers, it is of importance that the equipment should be periodically washed, to remove dirt and other material that would show up in the finished paper. When running colored papers, the coloring is commonly done in the beater; and to the beaterman falls the task of seeing to it that every beater is washed free from stock carrying any color, before furnishing stock for a different color. This precaution is not restricted solely to the beater but applies also to all the equipment through which the stock passes—head boxes, spouts, chests, pumps, and refining engines. Moreover, beating equipment ought never to be shut down for more than a day without thoroughly washing out every part of it. The stock that adheres to the beater becomes very hard on drying, does not readily recover its water, and comes off in lumps, which will reach the paper-machine wire to some extent and cause

trouble and lumps in the paper. The fine-paper mills have a complete wash-up of the entire beating equipment at frequent intervals, regardless of any shutdown or change of color. In some cases, the spouts are constructed entirely of copper, with many hand holes; the chests are surfaced with the best glazed-tile lining, and all inner surfaces are kept clean. Sand traps and pockets of all kinds should frequently be cleaned, to remove heavy particles of dirt and metal.

29. Use of Paint.—When the parts of wooden tub Hollander beaters are delivered by the builders to the mill, the metal parts are coated with white lead, and the wood parts, including the filling strips between the roll bars, are heavily primed with oil and white lead, for the purpose of preventing rust of the metal parts and the shrinking or checking of the wood parts. The outside of tub and curb are commonly finished with shellac and spar varnish; the inside of the tub may be finished with oil. In fine mills, during the periodic shutdown for cleaning, say once a year, the inside surfaces of the beater, including both roll and bed-plate, are both thoroughly scoured free of the thin film of slime that collects from the stock; and the end spiders, or heads, of the beater roll are thoroughly scraped, to remove slime and rust, and are coated with red lead or some other anti-corrosion paint. It is claimed that aluminum bronze, properly applied, gives excellent service. Where cleanliness is of prime importance, it is generally the custom not to allow the stock to come in contact with wood or with a corrosive metal at any time; and in these cases, the wooden tub is lined with a non-corrosive sheet metal (copper), brazed at the joints, and roll and bed-plate are equipped with bronze bars. The roll heads are cast in bronze, or if cast in iron, they are sheathed as is the wooden tub. To make clean paper, the beater room must be *kept clean*, and the beaters, chests, etc., thoroughly cleaned periodically.

30. Swelling of Wood.—The tightness of the wood tub, and the accuracy of form of the beater roll, depend upon the swelling of the wood due to moisture. It is the swelling of the wood strips between beater-roll bars that holds the bars fast. This swelling must have taken place before the roll is finally ground; for, however accurate the roll may be when dry, it will be thrown out of round when the wood strips are swelled. Moreover, a roll once put into service and ground to fit its bed-plate cannot be allowed

to dry; because, on putting it back into service, although the wood strips will swell again, they will not restore the roll to its former shape. If allowed to dry, it would be found seriously out of round and would have to be reground. Accordingly, a beater when shut down must have water in it, and the roll must be turned over once or twice each day to keep it in shape.

BEATER-ROOM EQUIPMENT

CHESTS AND PUMPS

31. Other Equipment Necessary.—In the preparation and supply of stock or stuff to the paper machine, there are several different types of equipment necessary besides the beaters. Since the beater has to be alternately filled (furnished) and discharged (dumped), which is an *intermittent* process known as the **batch process,** and since the paper machine, on the other hand, draws stock *continuously*, there must be, in practically every installation, several beaters feeding a single paper machine. The intermittent supply of stuff from the beater is converted into a continuous supply through storage tanks (chests) and pumps. Gravity is taken advantage of wherever possible; but in practically all mills, stuff pumps are used for forcing the stock from the chests to the refining engine or to the paper machine. In addition to the above, there are auxiliary apparatus of various kinds, which are used in connection with beaters, or are used for regulating the flow of stock.

32. Mixing Chest.—Mills making low grades of paper, as for example news, use their beaters for scarcely any other purpose than to break up the laps of stock or to pulp the dry broke. They usually depend on the refining engine to prepare the stock for felting on the paper-machine wire. In some cases, the stock comes from the pulp mill in slush form, and is *mixed* in a tank or chest before being pumped to the refining engine. One form of such a mixing chest is shown in Fig. 10. The peculiar feature of this chest is the cylindrical coffer *A*, placed inside and rigidly supported from the walls of the chest. The agitator *B* is driven at a high speed, and is designed to propel the stock downwards. The bottom of the chest is deeply dished. Thus the stock receives more or less violent agitation and a thorough mixing. The stock outlet is at *O*, and the washout is at *W*.

33. Stuff Chests.—Stuff chests, shown at *E* and *J*, Fig. 20, are built in many different ways. The early designs were the same as an ordinary water tank, cylindrical in form, and made up of two heads, and with straight planks and staves, held tight to the circumference of the heads by iron hoops. Although this

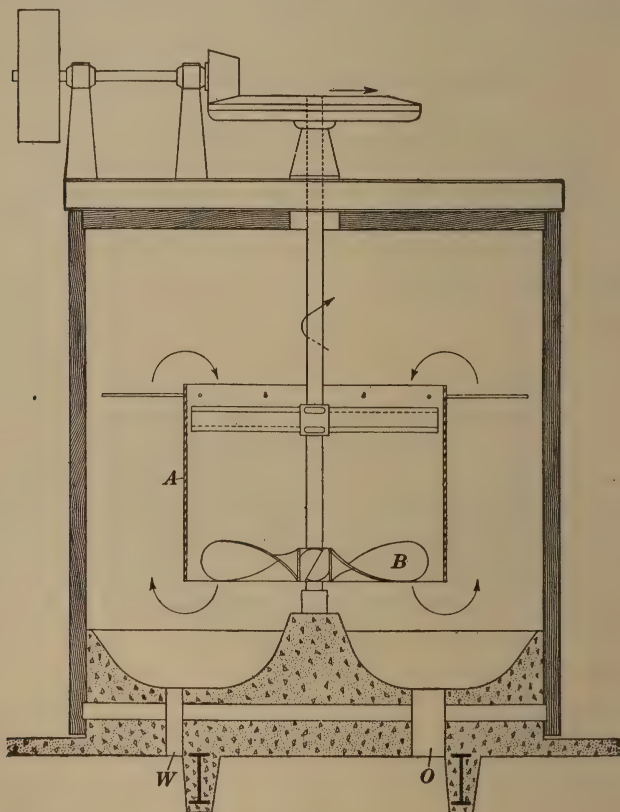


Fig. 10.

kind of chest is still very often found, it is being replaced by more carefully designed chests; partly because chests of larger capacity are now demanded in mills of large production, and partly because the different character of modern paper stock requires somewhat closer attention to the design of chests and to the materials of which they are constructed.

34. A very good type of stuff chest is shown in Fig. 11. This is a so-called *vertical chest*, built in cylindrical form, of concrete

or brick, and lined inside with glazed tile. To set the tile lining properly requires the highest degree of skill on the part of the mason; because the surface has to be accurately smooth, and all

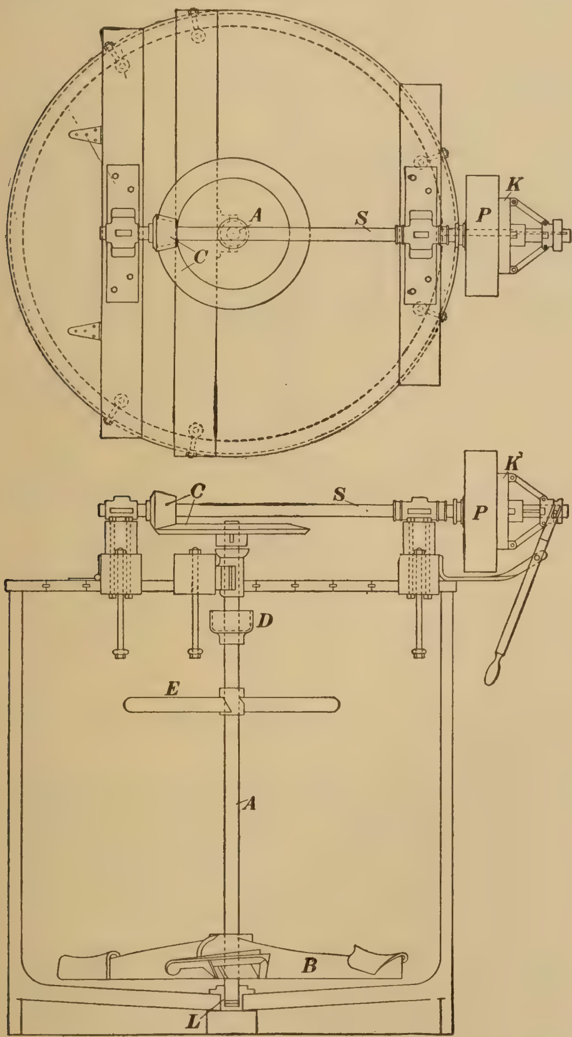


Fig. 11.

the joints must be perfectly pointed with cement. In mills using a great deal of clay in the stock, this feature is especially important. The base of the chest has a fillet on the inside, to prevent

the lodging of dead stock at the juncture of side wall and bottom; and the bottom itself is dished instead of being flat. Both the service outlet and the sewer outlet are placed near the center of the dished bottom, so all the stock can be run out when changing orders, changing colors or shutting down. Similar chests are often made of wood, preferably cypress.

A vertical shaft *A*, whose center line coincides with the center line of the chest, turns in a step bearing *L*, usually made of lignum vitæ and set in the bottom of the chest. To this shaft is attached a series of agitator arms *B*, so designed as to throw the stock outward and upward along the wall of the chest. At a higher point on the shaft *A* is another set of arms *E*, designed to throw the stock downward at the center. Arms *E* are in use, of course, only when the chest is filled to their level or higher. A

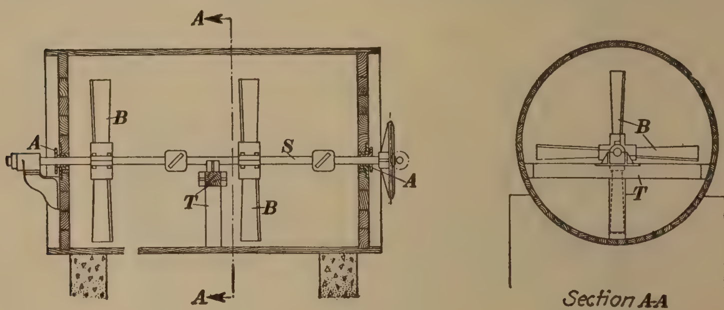


FIG. 12.

cup *D* catches the excess oil that falls from the upper bearing of the vertical shaft.

Supported over the chest on a bridge-tree is a shaft *S* and pulley *P*, with or without a clutch *K*, which drives the agitator through a cone pinion and crown gear *C*. For a chest 12 feet in diameter and 10 to 12 feet deep, an agitator of this type should be driven at about 27 r.p.m., and will require from 6 to 8 h.p. In mills making a good grade of paper, it is very important to have the chest well covered, as a guard against dirt. Somewhere in the top, however, there is provided a peep hole, illuminated with an electric lamp, so the beaterman on the floor above can see at all times how full the chest is, and whether or not the agitator is running.

35. Horizontal Chest.—The vertical chest shown in Fig. 11 is preferred by some to the horizontal chest shown in Fig. 12, but

the latter type is by no means uncommon, and it may be required when there is but little head room. As illustrated, it is a cylindrical wooden tank, built on its side. The same type is also built of brick or concrete, without the upper part being arched over, the sides being carried straight up from the level of the center line of the agitator shaft. The agitator shaft S is horizontal; it carries arms B and is driven from the outside. T is a support for the center bearing. It is claimed that the horizontal chest produces more uniform and quicker mixing.

36. Packing Gland.—Fig. 13 shows a typical packing gland, in which the agitator shaft runs; it is adapted to either vertical

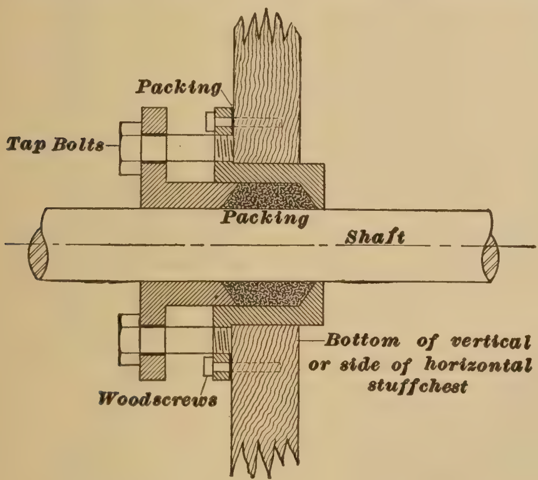


FIG. 13.

or horizontal stuff chests, and prevents leakage. Such a gland is used in vertical chests when the driving gear is below the chest; otherwise, the bottom of the agitator shaft is usually set in a step bearing in the bottom of the chest.

37. Stuff Pumps.—The work done in lifting paper stock from a lower to a higher elevation, as at points F and K in Fig. 20, requires that the amount of stuff delivered per minute shall not vary, whether the pump is drawing from a full chest or from one that is nearly empty; under such conditions, the plunger pump is used. Each stroke of a plunger pump—sometimes called a *displacement pump*—admits and discharges a fixed volume of stuff. Plunger pumps are designated as single (or simplex),

duplex, or triplex, according as they have one, two, or three cylinders. Centrifugal pumps are coming to be largely used for pumping stock. Full descriptions of pumps will be found in Part 1, Section 6 of this Volume, and in Part 1, Section 1, Vol. V.

38. A duplex plunger pump is represented in Fig. 14. It is driven through pulley *P*, either with or without a set of reducing gears, according as the duty of the pump is low or high. By means of a crank and connecting rod *T*, a long plunger *K* is moved up and down in the cylinder *C*, one on each side of the pulley. As the plunger rises, it leaves a partial vacuum behind it, which draws the stuff into the cylinder at the suction (or intake) end. When the plunger reverses its movement and begins to descend, it closes the suction valve and forces (discharges) the stuff in the cylinder through the delivery (discharge) outlet.

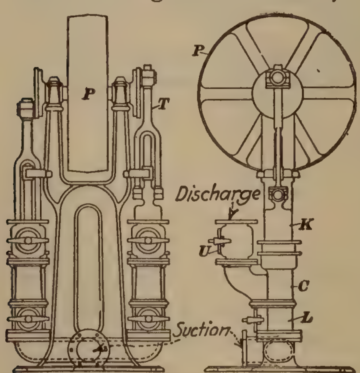


Fig. 14.

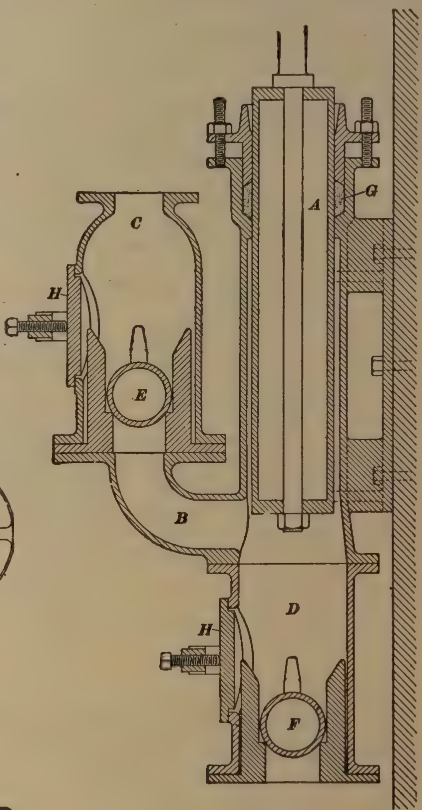


Fig. 15.

39. The manner in which the plunger pump works is shown in detail in Fig. 15, which represents a section through the cylinder of a simplex pump. The plunger *A* is long and hollow; and when in its lowest position, as shown, it occupies almost the entire volume of the cylinder *D*. The plunger runs through a packing

gland *G* at the top of the cylinder. Directly below the cylinder is a hollow ball *F*, which acts as a valve, admitting stuff to the cylinder as long as the plunger moves upward. As the plunger starts to rise from its lowest position, it reduces the pressure behind it. The difference in pressure on the top and the bottom of the ball causes it to rise from its seat, and causes a flow of stock upward, following the plunger. When the down stroke begins, the pressure on the top of the ball is greater than that beneath it; this forces the valve (ball) to its seat, which prevents the stuff from flowing back through the inlet pipe. As the plunger descends, the pressure increases; the stuff confined in the cylinder must go somewhere, or the plunger must stop, or the cylinder must burst; so the stuff flows through the discharge connection *B*, lifts the discharge valve (ball) *E*, and discharges through a pipe connected at *C*; this action continues until the plunger has reached the full limit of its down stroke. When the plunger again begins to rise, the pressure above valve (ball) *E* is greater than beneath it; this causes *E* to close (fall back to its seat), and keeps the stuff from flowing back from *C*; valve *F* rises, and the cycle is repeated. Both ball valves are made accessible by hand holes, covered by plates *H*, which are held tight against gaskets.

40. Caution.—In operating a plunger pump, always keep in mind two very important precautions: First, never allow it to pump against a closed valve, for, otherwise, something must give way and serious damage must result; second, be sure that the stuff being pumped is free from foreign substances, such as small pieces of wood or rubber hose, which may get under the balls and cause the ball valves to leak.

40A. Centrifugal Stuff Pump.—Fig. 16 illustrates a double suction volute type of centrifugal stuff pump. The stuff flows by gravity through the opening indicated by dotted circle and through dividing passages *A* to the eye of the side plates *C* into both sides of a rapidly revolving impeller *D* which imparts a high velocity to the liquid leaving the tips of the impeller vanes, discharging into a spiral volute *E* which surrounds the circumference of the impeller and which converts the high velocity into pressure. This causes the stuff to flow through the opening *F* into the discharge pipe. This type of pump gives a continuous even flow without any impulses or shock, flow can be controlled

by a valve in the discharge line to get reduced capacities and takes power in proportion to the capacity required. The flow can be entirely stopped for short periods by the valve in the discharge line without damage to the pump or pipe line. *G* is a pet cock to vent air while priming the pump. Water is led to the stuffing boxes *H* under slight pressure to keep the packing cool and prevent entrance of air into chamber *B*, due to slight vacuum created by the impeller. This type of pump is usually coupled directly to the shaft of a motor running at some speed between 900 and 1800 r.p.m. It can also be belt driven.

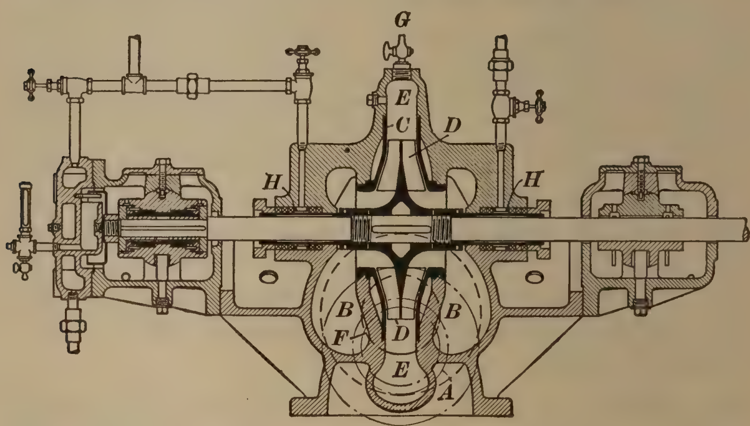


FIG. 16.

QUESTIONS

(1) (*a*) What were the early methods of beating? (*b*) When was the beater invented?

(2) What processes are carried out that are incidental to beating?

(3) Suppose the roll spindle, Fig. 1, to rest at the center of the lighter bar *D*; if the rod *K* has a thread of $\frac{1}{4}$-in. lead, the worm gear *L* has 20 teeth, and the hand wheel *M* is given one-sixth of a turn, how far is the roll lifted from the bed-plate? Ans. $\frac{1}{960}$ in.

(4) Explain the circulation of stock in the beater.

(5) What are the objections to steel bars, and what other materials are used?

(6) In what respects do the Horne and Umpherston beaters differ from each other and from the Hollander?

(7) Describe a type of beater other than those mentioned in the last question, and give its advantages and its disadvantages.

(8) Would you prefer a vertical or a horizontal stuff chest, and why?

(9) (*a*) Why is the plunger type of pump well suited to pumping paper stock? (*b*) What precautions must be observed in operating it?

(10) What must be the minimum diameter of a cylindrical stuff chest under the following conditions? It is to hold two beaters of stock, each of which is to dump 1200 lb. of bone-dry stock, mixed with sufficient water to make its consistency 3% (see Art. **69**); the total head room in the basement is 15 ft. 3 in.; 18 in. must be left under the bottom of the chest for piping, and the stock level must be kept at least 18 in. from the top of the chest; the bottom of the chest is 4 in. thick, and the weight of a cubic foot of stock may be taken as 62.5 lb. Ans. 12 ft. 4 in.

AUXILIARY APPARATUS

41. Regulating Box.—The stuff pump must deliver a constant quantity, equal to the maximum amount of stock required for the machines. Provision must be made for times when less than maximum capacity is wanted. In Fig. 17 is shown in detail a very simple form of regulating box, which may be used as at *G*, Fig. 20. This is simply a wooden box *A*, divided nearly in halves by a partition *B*. The part *ab* is cut lower than the part *bc*, and the opening thus left is provided with a gate *G*, which can be adjusted by means of screw *S*, to close all or a part of the opening. The top of the gate *G* may be raised higher than the partition at *bc*. The partition *D* is higher than *bc*, but lower than the top of the box. When more stock is pumped into the box at *E* than is wanted in the Jordan (or the paper machine), the gate is raised until the excess stock passes over *bc* into compartment *F*, then down pipe *H*, and back to the chest. If the stock is too thick, water may be added through pipe *W*. There are many designs of regulating boxes; some others are described in the Section on *Paper-Making Machines*, Vol. V.

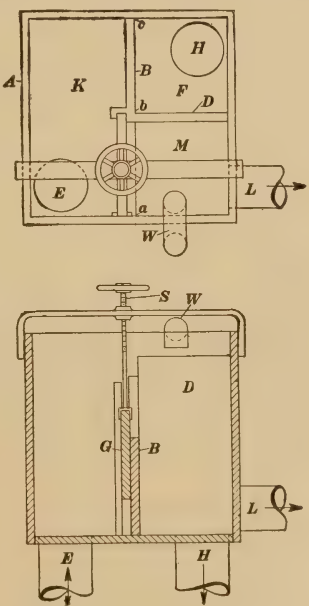


FIG. 17.

Some mills even have consistency regulators, so the stock pumped to the Jordan regulating, or flow, box is of very nearly constant density. A complete description of such an automatic

regulating device may be found in Section 7, Vol. III; it is briefly described in this Section in Art. **81**.

42. Washing Cylinder.—It is sometimes necessary to wash stock in the beater; or to increase its density (thicken it) by removing water. This is done commonly by means of a washing cylinder, such as that described in Section 1, *Preparation of Rag and Other Fibers*. This attachment is a set of scoops in a wire casing, which can be raised and lowered; it is caused to rotate, so as to dip up water without removing fiber.

43. String Catcher.—The string catcher is mounted in the tub, in front of the roll, and acts in the same manner as the racks at the inlet of a waterwheel. A row of fingers, reaching to the bottom of the beater, is mounted on a shaft that spans one side of the tub, and these are raised by means of a hand wheel and quadrant. The fingers are held in position, when down, by a pawl, which engages with a ratchet, which is on the same shaft as the wheel. The fingers are counterbalanced by a lever and weight.

44. Continuous Beater Attachments—Shartle Attachment.—This consists of a casting that was designed to replace the back-fall of the ordinary Hollander beater. The surface toward the roll is perforated, and means are provided for the discharge of stock from under this back-fall. Assuming that the object of beating is to reduce the stock in fineness, or length, the perforations are so arranged that when the desired fineness has been reached, stock will begin to pass the holes and on to the spout; as fast as this occurs, fresh stock can be added to the beater, which is thus converted from a batch to a continuous machine.

45. Bird Attachment.—Similar in principle to the Shartle, is the Bird continuous beater attachment, a perforated revolving drum being substituted for the perforated face of the back-fall. The drum is mounted in the channel of the tub that is opposite to that of the beater roll; it has perforations distributed uniformly over its face and over the end that faces the midfeather. The other end of the drum is open; and the stock that flows into the drum through the perforations is discharged through this end into a spout, which extends through the side of the tub, to a box outside the beater; the level of the discharge is governed by an overflow dam. The rate of discharge is governed by two factors:

the size of the perforations relative to the fiber-reducing power of roll and plate; the difference in level between the stock circulating in the tub and the stock discharging from the spout. As rapidly as the stock is reduced by beating and discharged through the drum, fresh stock is added to the beater, thus making the process a continuous one. As with the Shartle attachment, it is assumed that the stock is beaten when the fibers have reached a certain fineness, approximately, and these attachments work most satisfactorily when this assumption is substantially correct; they are best suited to very coarse papers, such as roofing felts, paperboard, and the like, and to the re-working of broke.

46. The Griley-Unkle Attachment.—The Griley-Unkle continuous beating attachment is also based on the assumption that the object of beating is to reduce the paper stuff to a certain degree of fineness. In this design, the perforated plate that separates the stock is located in the hood, or curb, of the beater, above the side of the tub and on the front side of the beater roll. The perforations are kept clear by means of a series of plates, which are made to slide over the perforations (like the damper slides of a cook stove), and which are driven by the action of a small crank that is belted to the roll spindle. The turning of the roll throws the stock off by centrifugal force; and as it becomes fine enough to pass through the perforations in the plate, it is collected in a trough, which is built under the perforated plate and entirely enclosed; from thence, it is delivered to the spouting system below the floor, through its own down-spout. A stream of water is provided in the collecting spout, to thin the stock, so it will flow in the spouting system. The field of application of this attachment is similar to that of the two previously mentioned.

A particular application of this device is in the reduction of old papers, to prepare them for incorporation in the sheet, when this can be done without the direct action of the roll on the bedplate. If the slapping of the roll bars is relied upon to break up the stock, and this can usually be done in substantially the same length of time as under the old method of setting the roll down to working position, there is an approximate saving of 20% in power.

47. The Roll Counterpoise.—An example of the roll counterpoise was shown in connection with the Marx beater, Fig. 7.

A graduated arm A is so hung that it gives a great leverage to the weight supported near one end of the lighter-bar L. The arm A is a lever of the first class, the power arm being the horizontal distance from o' to b', and the weight arm is the horizontal distance from o' to a'. Lighter-bar L is a lever of the second class, the power arm being the horizontal distance from o'' to b'', and the weight arm is the horizontal distance from o'' to a''. The whole constitutes a compound lever having a velocity ratio of $\frac{o'b' \times o''b''}{o'a' \times o''a''}$, which varies with the position of the weight W on the arm A; and more or less of the weight of the roll can thus be counterbalanced. With the weight W kept in a particular position, the bearing force of the roll on the bed-plate is constant. The action of the roll on the stock can, of course, be varied by moving the weight.

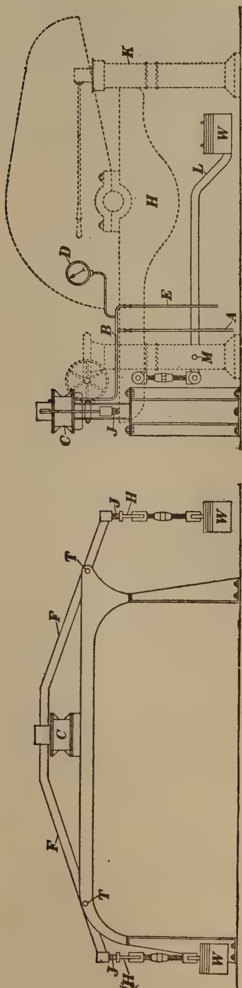


FIG. 18.

48. The Wallace-Masson Beater-Roll Regulator.—With a given design of beater and a given type of filling in the roll and bed-plate, an effort is made to control the operation of the beater by so governing the adjustments of the roll that the roll will exert a given pressure on the bed-plate; the counterpoise shown in Fig. 7 is one method of accomplishing this. Another method is the Wallace-Masson beater-roll regulator, shown in Fig. 18. A frame spans the entire tub, in a line parallel to the axis of the roll spindle; it carries two pivot bearings T, in which are hung two levers F, both of which are connected to the piston rod in the hydraulic cylinder C. Levers F bear, at their outer ends, on top of the lighter-bars H. The latter are counterpoised by means of levers L carrying weights W; and weights W are made sufficiently heavy

to balance the entire weight of the roll, spindle, lighter-bars, and bearings, and the belt pull also, if it be downwards. The pressure of the roll on the bed-plate is thus independent of the weight of the roll; it is developed by admitting water, under pressure, to cylinder *C*, through admission pipe *A*, and relieving through exhaust pipe *E*. The exact pressure applied to the stock is thus registered by the pressure gauge *D*. By making *D* a recording gauge, a record may be had showing exactly what pressures were used at every minute of the day; and it will also serve as a basis for framing the instructions for beating. Since the roll is completely counterpoised, the bearing is provided with an upper half, or top bearing, through which the force necessary to produce the desired roll pressure must be transmitted.

49. The Adjustable Doctor.—In the better constructed beaters, the doctor that is placed at the back side of the roll over the

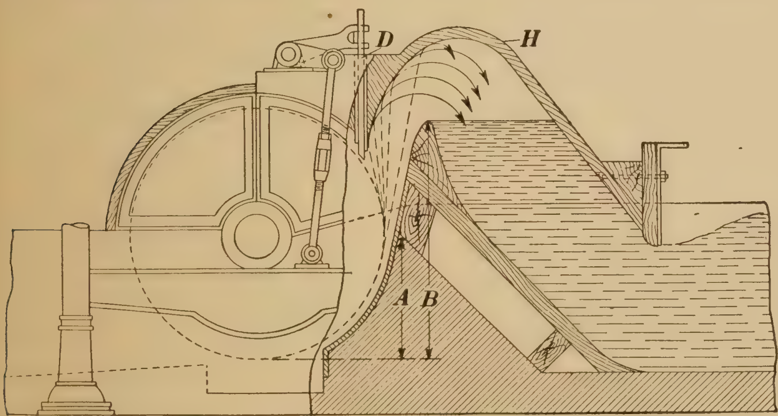


FIG. 19.

back-fall is adjustable. Those in charge of mills should watch the rolls carefully, to observe whether stuff is being thrown over from the back to the front; if so, the doctors should be adjusted to prevent this as much as is possible. While no great harm results from this carrying over, it tends to limit the capacity of the beater by reducing the speed of circulation of the stock. When adjusting the doctor, it should not be set so close to the roll that ordinary bumps bring the doctor and roll into contact.

In Fig. 19 is shown **Shlick's beater-hood attachment,** by which the Hollander beater may be so modified as to become a

new type. The adjustable doctor D is connected with the lighter-bar and in some cases to the roll journal, so that the doctor is raised when the roll jumps or is brought up by the wheel.

A high, deflecting hood or curb is indicated at H with correspondingly high back-fall, which, together with an elongation of the midfeather and heightening of the tub, increases the circulation of the stock. The increased height of the back-fall is shown at A and B. Many such variations are being developed and experimented with at the present time.

BEATER-ROOM LAYOUT

50. Fundamental Conditions.—It is probable that there are no two beater rooms in this country that have the same arrangement of beaters, chests, refining engines, mixing tanks, etc. The kinds of pulps used, the form and manner in which the stock is brought to the beater room, the method of beating, the design of the building and the arrangements of the other parts of the mill, changes in arrangement or rebuilding of old mills, power conditions, size of the paper machines, and many other factors, affect the beater-room layout. In general, however, there are certain fundamental conditions which are observed and which are considered when designing a new mill or rebuilding an old one. The distance between the beaters and the chests should be as short as possible, and the down spouting should be (as nearly as possible) in straight lines with no sharp turns. The pumps should be close to the chests, and the stuff-boxes and flow-boxes should be close to the pumps, refining engines, and chests. Long drives or shafting are to be eliminated wherever possible. Two beaters, or even one, to one paper machine are often found in small mills or in mills where the capacity of the paper machine is not large. When the capacity of the machine is very large or where a considerable amount of beating has to be done on each furnish of stock, the number of beaters to one machine may be as large as eight. In general, it may be stated that good design calls for a small number of beaters for machines of low capacity and a relatively large number for machines of high capacity, or where the stock requires long beating.

51. Diagram of Layout.—For the purpose of illustrating the general relationships of the various pieces of equipment in the

beater room, a layout of four beaters, two chests, flow-boxes, a refining engine, and pumps is shown in Fig. 20. The beaters *A* are arranged in a straight line, and the dumping valves discharge into vertical down spouts *B*, which lead to a collecting spout *C* that runs under the beater floor, almost horizontally. The spout *C* should have a slight pitch in both directions toward the point of its junction with the single down spout *D*, which leads to the chest *E*. In the operation of the mill, assuming

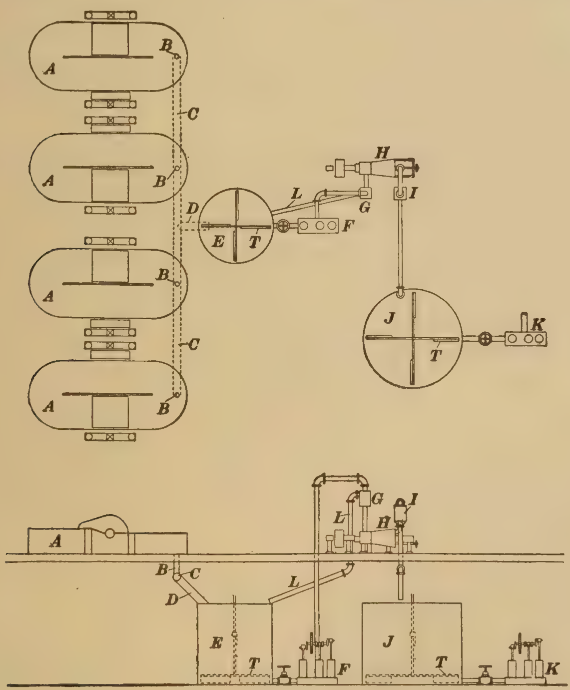


FIG. 20.

that fresh stock is furnished to all the beaters, they would be furnished in rotation, and would be dumped in rotation also. The stock thus passes in batches to the stuff chest *E*, which is built large enough to hold at least two beaters of stock, and which acts as a reservoir. Leading from the bottom of chest *E* is an outlet, through which the stock is drawn in a continuous stream to the pump *F*, which raises the stock to a flow-box *G*, placed above the Jordan refining engine. The flow-box is provided with a regulating device and an overflow pipe *L*; the

latter returns to the chest *E* whatever the pump *F* throws that is in excess of what the paper machine requires to pass through the refining engine. The refining engine *H*, which will be described later, discharges in a continuous stream into a box *I*, by means of which the pressure imposed on the stock while passing through the refining engine can be governed; and from box *I*, the stock falls to the second stuff chest *J*. This last is the reservoir from which the paper machine draws its supply, through another pump *K*, just as chest *E* is the reservoir from which the refining engine *H* draws its supply; hence, *E* is known as the **Jordan chest,** and *J* as the **machine chest.** In many installations, box *I* is not included. Both of the chests *E* and *J* are provided with agitators *T*.

It is customary to place the beaters in pairs, as shown in the illustration, with pulleys adjacent. In this arrangement, the drivers are least in the way, and the free space left between beaters may be made sufficiently wide to afford trucking way when desired. This arrangement permits of a group drive, though the beaters may be driven in pairs or individually by motors. The group drive tends to put a more uniform load on the motor, when a motor is used as a source of power. Water wheels, when used as sources of power, are commonly connected to beaters in groups; this sometimes necessitates complicated belting and long lines of shafting, all of which consumes power and involves expense for maintenance.

FURNISHING THE BEATER

52. Composition of the Furnish.—The mixture of the various materials that are blended in the beater, and of which the paper is ultimately composed, is called the **furnish.** The chief constituent of this furnish is, of course, the fibrous material; and to this may be added rosin size, mineral substances, called **loading** or **filler,** coloring matter and alum (aluminum sulphate) in varying proportions, sodium silicate, starch, etc., as required. The kind of paper to be made determines the presence or absence of one or more of these non-fibrous constituents of the furnish, but nearly every paper requires the use of alum. The operation of filling up or charging the beater with these materials is called **furnishing.** The furnishing must be carried out in such a

manner as to form a moving mass of slush throughout the process, which must provide for carrying the stock under the roll. It is a great advantage to have one kind of stock in slush or wet form, which can be drawn from a pipe or dug from a stock box, so that the circulation around the tub will begin at once. Lacking this, it is often necessary to make the initial slush by forcing some pulp under the roll with a paddle, after a small quantity of water has been put in; water alone will not carry dry or pressed pulp under the roll.

CONDITION AND HANDLING OF PULPS OR HALF-STUFF

53. Condition.—The pulp or half-stuff, the fibrous part of the furnish, may come to the beater room in many forms: dry or wet broke from the paper machine; pulped waste paper in cars from the drainer or in slush form from storage tanks; wood pulp in dry sheets, in rolls, or in dry or semi-wet laps; wet half-stuff in cars from the drainers; or various pulps in slush form or from thickeners. The handling of the stock in furnishing is as varied as is the beater-room layout and the form in which pulp reaches the beater room.

54. Pulping Broke.—In many mills, the beating equipment is utilized to pulp the dry waste of the mill. This is done in two

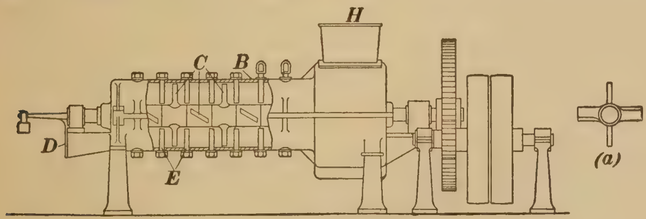


FIG. 21.

different ways: (*a*) One or two beaters of the set are used exclusively as broke beaters, a small quantity of broke being dropped into the chest each time a beater of fresh stock is dumped; or (*b*) a proportion of dry paper is incorporated with each furnish, and all beaters of the set are used alike. By either plan certain beating capacity is withdrawn from the beating of fresh stock. In many mills some independent form of waste-paper pulper is preferred, which will deliver, for the furnish, stock that has

been thoroughly wetted and reduced to a pulp. One type of pulper for this purpose is shown in Fig. 21.

55. This pulper consists of a hopper *H*, Fig. 21, mounted on a barrel *B*, the axis of which coincides with the axis of a shaft that is driven by a strong gear-reduction set. The shaft carries radial arms *C*—see detail at (*a*)—which turn with their ends very close to the inside of the barrel *B*. The dry paper enters the hopper with water and, usually, with steam also. The mixture is driven toward the barrel by a worm-screw conveyor, under the pressure of which it is forced through the barrel to the counterweighted discharge door *D*. During its passage through the barrel, it is worked by the radial arms *C*. These arms are cast with their forward face in the form of a cam, which tends to pinch the stock against the inside of the barrel and the pins *E* and to roll it at the same time. The result is a moist pulp, which readily mixes with the other stock, when furnished to the beater. In many cases, it is possible to withhold this disintegrated paper from the beater until all of the fresh stock has been beaten, thus saving very greatly in beater capacity; it is then added with enough allowance of time before dumping to insure thorough mixing.

Another type of waste-paper pulper, also used for mixing wood pulp, is described in the Section on *Treatment of Waste Papers*. It is essentially a beater, with a paddle wheel on one shaft for circulating stock, making about 14 r.p.m. The other shaft is set with thin blades and makes 115 r.p.m., slushing the stock and mixing it.

56. Frozen Pulp.—Frozen laps of wood pulp are a source of considerable trouble in the beater room. It is difficult to break up such laps by hand, and it is not always convenient to store them indoors until they thaw; while to thaw them with steam is expensive. If they are fed direct to the beater, damage may result. To facilitate the furnish and to aid the beater in converting the laps into slush of the proper consistency, the use of a machine is advisable. A patented shredder that is widely used for this purpose is illustrated in Fig. 22. The stock is fed over the feeding table *A*, and is passed on by corrugated roll *B*, while it is torn into fragments by the blades *C*. These blades have a serrated edge, and are so mounted on an arbor as just to clear

the steel shoulder *D*, which is mounted on the edge of the feeding table. This machine is rated to consume less than 30 h.p. in the preparation of 5 tons of dry stock per hour.

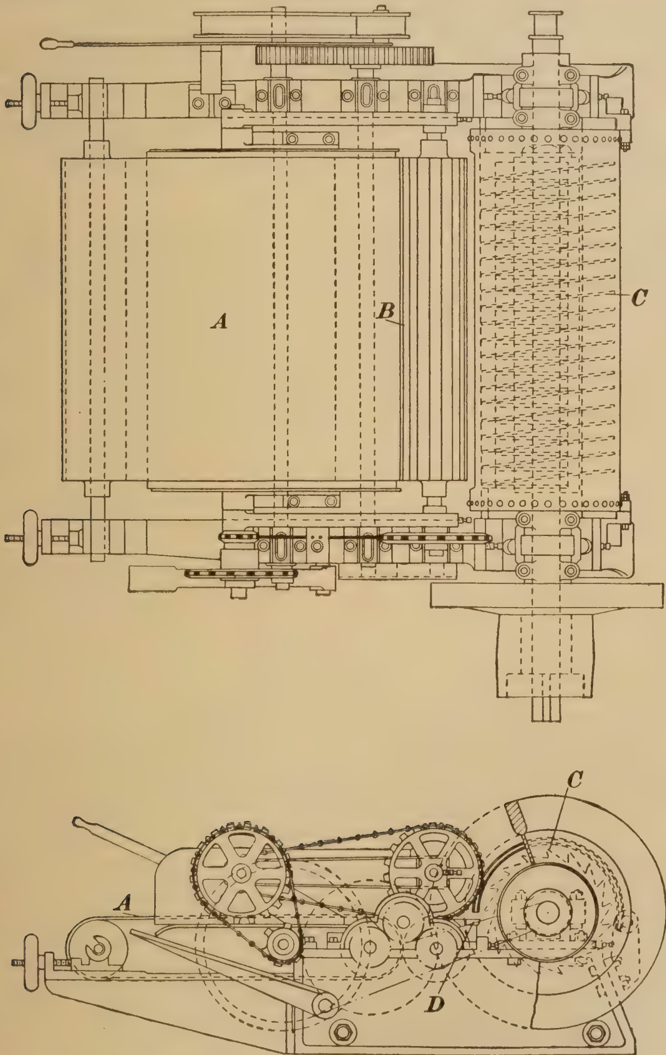


FIG. 22.

57. Slush Pulps.—It is common practice in news mills, and in some mills making higher grades, to furnish the stock in slush form. This is done where the preparation of pulp is under the

same management as the paper mill and the pulp mill is conveniently located, so that the pulp may be pumped directly to the beater or fed by gravity from storage. Stock in slush form is generally mechanical (*i.e.*, groundwood), sulphite or soda pulp, or pulped waste papers. Where more than one slush pulp is furnished to a single beater, separate pumps and piping are used. It is customary to eliminate some of the water from these pulps before furnishing them to the beater by means of various types of thickeners, as explained in *Treatment of Pulp*, Section 7, Vol. III.

58. Dry and Semi-Dry Pulps and Half-Stuff.—Practically all other pulps or stock are charged or furnished into the beater by hand. Water is first put in the beater, and then the pulp or half-stuff is added. Laps or sheets are broken up, and care is taken that large lumps of stock are not permitted to go under the roll. Half-stuff is dug out of drainer boxes in which it is pushed to the beaters. Dry broke is added slowly, and with care not to jump the roll. Pulp in rolls is generally added by pulling out the center of the roll and pushing the end of the continuous sheet under the beater roll. The roll of pulp is held pointing towards the beater roll, which pulls the pulp in a continuous sheet from the center of the roll. In other cases, the roll may be run on a piece of pipe, held by two men, or in a frame.

ORDER OF FURNISH

59. Usual Order.—There are many and varying ideas regarding the proper order for furnishing the different materials to the beater. If stock is available in slush form, it should go in first. If the stock is so thin that other stock added in the form of drained, rag half-stuff or dry pulp will not give the desired density, the excess of water is removed by the washer while the furnishing proceeds; then lap or roll pulp, or rags, or pulped paper is put in. Clay or other filler is usually added with the fiber or immediately after it. The order in which size, alum, and color are added varies with conditions; but, as a rule, the size is added early enough to allow for thorough mixing, and to have the effect of the size on the colors evident before the coloring has developed. Then the color is added and is well distributed, so that when the alum is finally put in, the coloring and sizing will be uniform

throughout the mass. Exceptions to this order will be mentioned in the Sections treating of *Coloring* and *Sizing*.

60. Loading.—Mineral loading, or filler, is included in the furnish to give the paper opacity, to give the paper a smooth surface or finish, to assist in the development of the color (principally in white papers), and in some cases, to increase the weight of the paper. The usual loading materials are clay, calcium sulphate, and talc. Clay and talc can be added to the beaters dry. Clay and calcium sulphate (crown filler) reach the mill in casks, and have to be weighed into the proper batches for adding to the beater furnish. Clay is also bought in bulk in carload lots. Talc comes in sacks already weighed. If clay is used, the most satisfactory way to handle it is to mix it carefully with water in proper proportions, have a tank of it (which acts as a reservoir) mechanically agitated, and draw a prescribed volume of this clay milk into the beater while the stock is traveling. Further information concerning this operation is given in the Section on *Loading and Engine Sizing*.

61. Sizing.—The treatment of stock with a substance that tends to make the paper water- or ink-resisting is called **sizing.** The substance usually, almost universally, employed, where the sizing is done in the beater, is a soap obtained by boiling rosin with soda ash. This is added to the beater either by using dippers or by first emulsifying it in cold water and then adding to the beater in the form of milk. The latter method is finding increasing favor, largely because of its convenience, and also because of the better distribution throughout the beater that can be obtained by running in the milk while the stock is traveling. The chemistry of sizing is very complex, and it is not thoroughly understood. The important fact for the beaterman to keep in mind is that two things are required in sizing: first, to add the size, and then to add the alum. Adding the alum (aluminum sulphate) to the furnish before the size has had time to become intimately mixed in all parts of the mass, defeats the sizing action. The subject is more fully discussed in the Section on *Loading and Engine Sizing*.

62. Coloring.—Adding the coloring matters is a part of the beaterman's duties. Here, again, the chemistry is very complex, and is still little understood, in some respects. Some coloring

materials are better developed by following the alum than by preceding it in the furnish. More of the common paper-mill colors are better developed by being added before the alum, while with some it makes but little difference which is added first. However, the practical way of running a mill is to have a fixed rule, one that is nearest right on the average, and which will not involve a lot of men in the complexities of chemistry. With this in mind, chemists and color experts seem to agree that the best practice is to add the size early in the run, to add the colors at a time that will permit of thorough distribution and development, and to add the alum as near to the dumping time as is possible. The fact that the slight excess of alum that is always necessary will cause sufficient acidity to attack the steel of the roll and bed-plate is one more reason for this order of adding these materials.

The matter of matching shades and choosing coloring materials involves a world of intricate technology, which will not be discussed here. The subject of coloring is treated in the Section on *Coloring*.

TYPICAL FURNISHES

63. Reason for Variation.—In order that the student may obtain a general idea of some of the principles involved in the furnishing and beating of stock for certain types of paper, a few illustrations are given. It must, however, be kept in mind that the method of furnishing, the order of furnishing, and the manipulation of the roll, will seldom be the same in any two mills, even on the same type or kind of stock. Experience has indicated certain general methods of procedure; but in a large number of mills, furnishing and beating are not under close technical control, and the skill and experience of the beaterman is relied upon to a very great extent. Variation in the quality or character of the raw materials obtained is also a factor that makes it difficult to maintain the same formula for any given kind of paper. There are, therefore, so many factors which affect the furnish and the actual operation of beating, that the examples given must be considered to be very general.

64. High-Grade Rag Bond.—Assuming the use of a 700-pound Hollander beater, half-stuff from number one "shirt cuts"

(a high grade of new, white, cotton shirt cuttings), an 8-hour beating for a high-grade, all-rag bond paper, and engine sizing sufficient for later tub sizing, the following procedure will give an indication of mill practice. Before adding any stock, or rather before dumping the previous beater, the roll is raised off the plate about 15 turns of the hand-wheel. This is necessary to give clearance for the bunches of stock. The beater is first filled about half full of water, which is carefully filtered, or strained through a cloth bag usually made of press felt. The half-stuff is brought up from the drainer room in "stock boxes," containing about 150 to 200 pounds air-dry fiber which, as it comes from the drainer, contains from 70% to 75% of water. The half-stuff is charged into the beater by hand, tongs, or forks, and in this case about 4½ boxes of stock would be used. Water is gradually added as the half-stuff fills the beater. When completely charged with half-stuff and water, the concentration or density of the stock will be between 4% and 5%. The stock in the beater is very lumpy and the surface is not smooth.

After about a half hour of circulation of the stock, the roll is lowered 5 turns. At each succeeding half hour, the roll is lowered 2 turns until it is 2 turns off the plate, at the expiration of 2½ hours. The rosin size is then added, (assuming that it is in milk form) from a measuring tank; 70 gallons of size, containing about 0.3 pounds per gallon are added, equal to 3% on the weight of the stock. It is preferable to strain this size while adding it. Strainers can be made by putting a bottom of machine wire or press felt on a shallow box about 2 feet square. By this time, the lumps of the stock have begun to disappear and the surface becomes more smooth. The roll is lowered by half turns each half hour until it is one-half turn off the plate. It is lowered a quarter turn at the end of the next half hour, and another quarter turn at the end of the next hour. The color, dissolved in hot or cold water as the case may be, and strained, is added. At the end of 6½ hours, the hand wheel is turned down another quarter turn, leaving the full weight of the roll on the stock. About 25 pounds of alum, dissolved in hot water and strained, is then added, and at the end of the 8-hour period, the roll is raised 15 turns, the valve opened and the stock is dumped to the Jordan chest, with some additional water to slush it down. This manipulation is modified to a considerable extent by different beatermen.

65. Mixed-Stock Furnish.—Some furnishes may require the use of two or more kinds of stock that require different beating treatment, such as rag stock and bleached sulphite in a 50% rag bond. It often happens that the two stocks are beaten separately, and mixed in proper proportions in the Jordan chest. Care has to be exercised that there is proper mixing; and it is generally necessary to have a special mixing chest, similar to that shown in Fig. 10. It is obvious that some such arrangement will produce better paper, for the severe beating treatment to which the rag half-stuff must be subjected may be detrimental to the sulphite. A similar manipulation is advantageous where rope stock and sulphate pulp are used in strong bag papers, or where rags and soda pulp are used in blotting papers. In some cases, it is a good practice, where the proportion of long fiber (requiring severe beating) is considerably greater than the short stock, to charge the former into the beater by itself, and it is partially beaten before the addition of the short fiber. This method is preferable to putting both stocks in at once, but it does not have some of the advantages of the separate beating, as described above, though it may give more uniform color.

66. Book Paper.—The furnishes for book papers will vary widely. Relatively cheap raw material must be used, and production is an essential factor. A rather high grade of book paper would consist of equal amounts of sulphite and soda pulps; these would be furnished to the beater by hand, and would receive a short beating of about 2 hours. For a 2000-pound beater, about 10 bundles of 55% air-dry sulphite pulp or about 1000 pounds of dry sulphite would first be added, and the beater then filled up with soda pulp. Some 500 pounds of clay would immediately be added, either dry or in suspension in water from tanks. This would give about 15% of loading in the finished paper. About 45 gallons of size would be added next from a tank, equal to 2% of the weight of the stock. Color would be added shortly afterwards, the roll lowered, and the alum added shortly before dumping. After 2 or 3 hours, the stuff is dropped to the Jordan chest.

Such a procedure or furnish is modified to a great extent where pulped magazine stock is used or where the pulps are available in the slush form. In some cases, the sulphite pulp is beaten separately, and the pulped magazine stock or slush pulps are

added in a suitable mixing tank or chest. Most book papers contain clay, or some similar loading material, and also small amounts of rosin sizing. It should be remembered that printing inks are made with oils, not water; hence, printing papers need not be water resistant. In some cases, bleached mechanical pulp is used in the furnish, particularly where the paper is to be used for current magazines of little permanent value; such pulp is usually added in slush form.

67. Newsprint.—In general, newsprint is made of about 70% to 80% of mechanical pulp, the remainder being sulphite pulp, both unbleached. Due to the necessity for low prices, costs must be kept to a minimum, and production is of paramount importance. This type of paper is therefore generally made in a mill having a convenient supply of pulp; and it is probable that a majority of news mills use the pulps in the slush form, and have little, if any, use for a beater, except as a mixing vat. Very small quantities of rosin sizing and alum are frequently added and, in case of "white" news, some blue dyes. Any further conditioning of the fibers is done almost entirely by one or more refining engines.

68. Coarse Boards.—Probably the larger proportion of the tonnage of coarse boards produced have "mixed papers" as their chief constituent. In the production of such boards as chip, binder's, cloth, trunk, etc., the waste paper is disintegrated in a beater or by special pulping equipment, and is fed direct to a refining engine. Where combination boards are being made, the stocks for the different vats is beaten separately and dropped to separate chests. On account of the rather peculiar treatment of stock for boards, some further information is given in Arts. **95 to 100.**

THEORY OF BEATING

ACTION, POWER COST, AND EFFICIENCY

69. Definitions.—Certain terms are used by paper makers in connection with the treatment that the fibers receive in the beating process. Such words as *shortening*, *crushing*, *brooming* and similar terms are freely employed in the language of the mill as though they were accurately descriptive of certain phases of beater action. Unfortunately, however, in spite of the fact that experienced mill men are able to produce at will close and dis-

tinctive results in the beater, accurate knowledge regarding precisely what happens is limited; consequently, an exact wording of the meaning of the terms applying to these results is very difficult. General definitions of some of these terms will now be given.

Half-stuff is the fibrous material (pulp) in condition to go into the beater. When this material has been beaten, it is called **whole-stuff** or, simply **stuff.** When the whole-stuff has been diluted and is ready for the paper machine, it is called **stock.** Sometimes the words stock and stuff are used interchangeably, but a distinction should be made between them, to accord with these definitions. Note that in addition to the fibrous material, stuff may include other materials, as sizing, color, loading (filler), etc.

By **consistency** is meant the per cent of *air-dry* paper material in the stock (or stuff); also called **density** or **concentration.** It is found by dividing the weight of air-dry fiber in any particular amount of stock (stuff) by the total weight of the stock (stuff). Thus, representing the total weight of the stock (stuff) by W, the weight of the bone-dry material contained in it by w, and the consistency by C, $C = \frac{w \div 0.9}{W} \times 100 = \frac{1000w}{9W}$, because the weight of bone-dry pulp is 90%, or 0.9, of the weight of air-dry pulp or stock (stuff).

Free stock is a mixture in which the fiber has been prepared in such a way that when delivered on a sieve it forms a mat through which the water readily drains; this is an essential characteristic of stock for fast-running paper machines, as for newsprint and for papers that are to be bulky or absorbent. **Slow stock** has been so prepared that, under the same conditions, the water drains from it slowly; it is also called *greasy* or *slimy*, because of the feel of the stock after very long beating. Such stock requires a slow-running machine and increased suction; it is suitable for bonds, writings and parchments. The terms **short stock** and **long stock** are relative. The fibers are shortened by being cut in the process of beating or refining, or both. A cotton fiber, perhaps $\frac{1}{2}$ inch long originally, may be shortened considerably and still be longer than a full-length wood fiber that is, say, $\frac{1}{8}$ inch long. Short fibers that are mixed with long ones tend to form a more closely felted sheet than long fibers alone. **Crushed fibers** are produced by such action of beater or refiner as may be thought of as *pound-*

ing. Fibers, and bundles of fibers, are sometimes split lengthwise into what are called *fibrillæ.* When this splitting affects only the ends, the fibers are said to be **broomed.** **Hydration** means the taking on of water by the cellulose fiber; it is induced by the mechanical action of the beating apparatus and the rubbing together of the fibers. Hydration results in a gelatinous film on the fiber, which assists in cementing the fibers in the sheet.

ACTION OF THE BEATER

70. Mechanical Action.—Before discussing the theory of beating, it would be well to consider the facts as to what results are obtained by beating. These results may be grouped into two classes,—mechanical and chemical,—which, when combined to a greater or lesser extent, produce the condition of the stock desired for proper felting of the fibers on the paper machine. The change in the physical structure of the fibers may best be illustrated by photomicrographs. It is to be noted that the cotton fibers in Fig. 23 are quite long and unbroken; whereas, in Fig. 24, the fibers are cut, bruised, frayed, broomed and split, and retain little of their former unbroken character. In this case, the stock was subjected to prolonged beating, to "draw-out" the fibers with a minimum of cutting action. In the case of a rag blotting paper, the tackle would be sharp, the consistency high, and the cutting action greater than the bruising. In Fig. 25 are shown some unbeaten sulphite fibers,[1] while Fig. 26 indicates the damage done to them by the mechanical action of the fly bars and bed plate. In the case of mechanical pulp, the beating results principally in a separation of fiber bundles. Beadle[2] has shown, by the measurements of samples of stock taken from the beater at frequent intervals during the beating process, that the fibers are reduced in length, and that this reduction takes place largely during the early part of the beating. It is, therefore, the general rule that, wherever there is any considerable beating, the physical structure of the fiber is changed by mechanical means. The fibers to be used for paper making are thus shortened, frayed, split, etc., either in the beater or in the refining engine, to permit of better felting or interlacing of the fibers on the paper-machine

[1] Characteristic fibers produced by the several processes from wood are shown in Section 1, Vol. III.

[2] Chapters on *Papermaking*, Vol. V, by Clayton Beadle, page 151, Fig. 29.

wire. The shake of the wire tends to form a compact and uniform fabric, which produces a better appearance and a more even surface for printing.

FIG. 23.

FIG. 24.

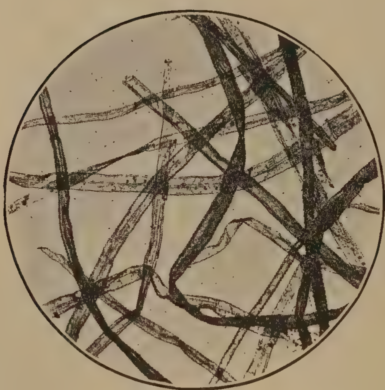


FIG. 25.

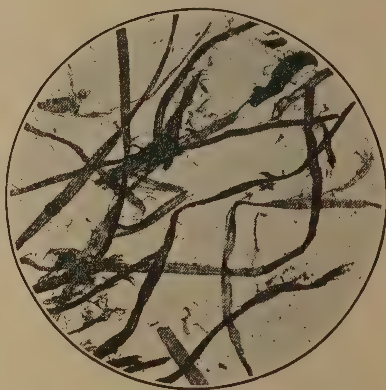


FIG. 26.

71. Chemical Action.—It is more difficult to describe or illustrate the chemical change produced in the fibers by beating. The simplest statement is that the cellulose fiber combines with water under certain conditions. This action is accelerated by agitation, by friction, or by treatment with certain chemicals. If carried to its extreme, this action results in a slimy, gelatinous mass, wherein all semblance of fiber structure has been lost; actual beating does not go this far, but some of this slimy substance is contained in nearly all high-grade papers. Glassine contains a high percentage of such hydrated cellulose, while

blotting paper, in which it would detract from the absorptive capacity, has a very small percentage. Stuff that has been beaten a long time is generally slow or wet. The effect of this at the paper machine is to require more suction on the machine suction boxes, and to produce a more compact, dense sheet, hard to dry, and likely to cockle in drying. The hydrated cellulose acts somewhat as a binding material, and it tends to increase the tensile and bursting strengths of the paper by serving as a cement or binder; it produces a hard, rattly, snappy sheet. When a soft, limp, absorbent sheet is wanted, the beating is done drastically and quickly, cutting the fibers rapidly, and allowing as little time as possible for the development of the slime or hydrated cellulose.

72. How the Results Are Obtained.—Bearing in mind the various results obtained by beating, as they have just been described in general terms, it is necessary next to consider the ways by which such results are reached; and this may be done: first, with reference to the practical operation of beaters in paper mills; and, second, with reference to the theories of beating that have been evolved to explain the facts, as well as to assist in making improvements on present designs of beaters.

Take, for example, the case where all of the pulps that are to compose the final paper are beaten together at one time, for this is the simplest case. After the beater has been furnished and the roll action started, there is nothing added or taken away; no change can be made in the speed of the roll; no change can be made in the form, hardness, or number, of bars in roll or bed-plate; the only manner in which the beaterman can influence the quality of the final paper is by his manipulation of the roll up or down, including not only his positioning of the roll, but also the length of time of treatment at any given roll adjustment. Upon this one factor, usually entrusted entirely to the skill of the beaterman, rests the outcome; that is, whether the final paper will or will not be of the required character, and whether the paper machine can or cannot run economically. The beater-man judges the progress of the beating by feeling the stuff with his hand, or by dipping out a small sample in a pan of about two quarts capacity, shaking the stock together with additional water, and observing the tendencies of the fibers to clot, or gather, or by using such instruments as have been recently devised to assist his judgement.

73. With the composition and the density of the furnish once fixed, low setting of the roll, giving violent, drastic, punishment to the stock, will result in the greater physical damage to the fibers. If this be maintained for a comparatively short period, and the beater then dumped, the resulting stock will be free, comparatively well formed in the paper, and the final paper will be soft, inclined to be fuzzy, weak in tensile and bursting strength, easy to tear, possessing low wearing endurance, and, unless especially sized, absorbent. Under the same conditions in the beater, if the roll be set lightly, and that setting be maintained for a comparatively long period, the resulting stuff will be slow, and, when run out into paper, will still be well formed, but more cloudy, and the final paper will be hard, firm in surface, strong, with high wearing endurance, and in much less need of sizing to make it resist water. A paper produced in the first way will not take a high finish in calendering, whereas a paper produced in the second way will readily take high calender finish. Either action of the roll maintained for a long enough period would result in slow stuff; but the two actions would not result in the same quality of paper, except when carried out almost indefinitely; in which case, the fiber would entirely disappear and a gelatinous mass would remain.

By far the most usual procedure, for the higher grades of paper, once the composition and density of the furnish have been fixed, is to begin the beating with a moderate setting of the roll and then gradually to lower the roll at intervals during the run. Where the beating is done in this way, the beaterman must decide how hard to set his roll at each change in setting, when to change the setting, and when the desired final result has been attained; great responsibility therefore rests upon the beaterman. The task is the more delicate because of the fact, revealed by experience, that results are retarded and sometimes destroyed by raising the roll (setting it less severely) during the run. The roll must never be brought upward, but always progressively downward, except at the end of a run, especially if no Jordan is used, when the roll may be raised a hair's breadth, while the fiber is brushed out.

74. These rules in beating have been developed through years of operation with rag stock, and with other long-fibered stocks, for the higher grades of paper. Since the general introduction of wood fibers for the bulk of commercial papers of all

kinds, refinement of practice in beating has tended to yield to rapidity, and the tonnage required of him leaves the beaterman little chance to attend to progressive roll settings. Most mills using wood pulps do their beating with a single setting of the roll.

The beaterman judges the setting of his roll by two means: first, by the number of turns of the adjusting hand wheel; and, second, more finely, by the sound that he gets by putting one end of a stick on the bed-plate chair and his ear to the other end. This same device tells him how well his roll fits the plate, and how accurately round the roll is ground.

75. Fibrage Theory.—Five years' experimenting by the Danish engineer, Dr. Sigurd Smith,[1] have led him to what he terms the *fibrage theory* of beating. As he points out, if a steel rod of square cross section is moved through a tub of stock, with its sharp edge forward, a certain amount of fiber will collect on that edge; and the character of the fiber and the density of the mixture in the tub determine how much fiber will thus collect. Similarly, as the beater roll turns, the bars advancing toward the bed-plate carry with them a certain amount of fiber collected on the edge. The roll bars then advancing across the bars of the bed-plate act on these fibers in a manner similar to the action of a lawn-mower on blades of grass; that is, it cuts some of them directly, but damages a great many more by fiber acting upon fiber within the mass that is imprisoned between the bars. Thus, if the consistency be thin, less fibrage will be collected on the edges of the bars; and a given distance between roll and bed-plate will result in less fiber damage than if the consistency be thick and the distance between roll and plate be the same. This conclusion has been borne out by actual beating in the mill.

Acting on this theory, Dr. Smith has designed a type of beating tackle to impose on the stock greater action without a proportional increase in the power required. He explains that to make the bed-plate wider would not increase the effective beating that could be done under given conditions in a given time, a fact that has been shown in mill practice many times, as he says; and he offers as the reason, that in going across a single plate no new

[1] The Action of the Beater in Paper Making, by Dr. Sigurd Smith, Journal of the Royal Society of Arts, Vol. LXXI, No. 3655, Dec. 8, 1922. *Paper Trade Journal*, Vol. 75, No. 26; Vol. 76, No. 1, Dec. 28, 1922 and Jan. 4, 1923. The *Paper Makers' Monthly Journal*, Vol. 60, No. 12, Dec. 15, 1922. Also in book form from *Pulp and Paper Magazine of Canada*, or Technical Association of the Pulp and Paper Industry.

fibrage can be collected on the edge of the beater bar, and a comparatively narrow plate suffices to treat as much fibrage as is collected at one time. By arranging two plates, however, with a properly designed space between them, new fibrage can be collected on the beater bars as they pass from the first plate to the second; thus the second plate can be made effective also.

76. The Circulation Theory.—Granted that effective beating depends mainly on frequent passing between roll and bed-plate by the stock, there are then two ways in which this may be accomplished: First, to increase the number of plates under the roll, or, what in principle is the same, to increase the number of sets of rolls and bed-plates in one tub; second, with one roll and bed-plate, to increase the speed of circulation. By traveling more rapidly around the tub, the stock is brought more frequently under the roll; conversely, a beater that will propel a given concentration of stock at a higher rate of speed will propel stock of a higher concentration at the same speed. Stock of the higher concentration, as has been pointed out, will receive more damage to the fibers in one passage under the roll than stock of the lower concentration, the setting of the roll being the same. Thus, there is a double advantage in the beater that is so designed that, with slight increase of power, it can propel the stock at a higher speed; the effective beating may be increased either by reason of higher *speed of circulation*, or by reason of higher *concentration*. In practice, the newer designs that have been offered accomplish much in both directions.

77. Most Efficient Degree of Concentration.—An ingenious method has been evolved for finding the consistency of stock that will enable a given beater to perform most efficiently; that is, do a given amount of work on the stock with the least expenditure of power per ton of paper produced. Based on the assumption that 50 times under the roll completes the beating, a series of tests were made on a given furnish at different consistencies, wherein the consistency, the speed of travel (circulation), and the power input to the motor, were measured; and these tests led to the following table:

Per cent consistency	Pounds air-dry stock	Speed of travel in feet per minute	Minutes required to turn 50 times	No. of dumps per 24 hours	No. of pounds air-dry stock per 24 hours	No. of tons per day	No. of horse-power-hours per ton
0	0	141	15.4	0.0	0	0.0	0.0
1	300	111	19.4	74.0	22,200	11.10	6.75
2	600	80	26.9	53.5	32,100	16.05	4.68
3	900	55	39.0	37.0	33,300	16.65	4.51
4	1200	33	65.0	22.2	26,600	13.30	5.64
5	1500	20	107.5	13.4	20,100	10.05	7.47
6	1800	10	210.0	6.85	12,330	6.16	12.18
7	2100	4	537.5	2.68	5,630	2.80	26.80
8	2400	1	2150.0	0.68	1,610	0.80	93 70

These figures plotted in the form of a chart are shown in Fig. 27. The chart brings to view more forcibly the fact that with this beater, and the particular stock with which it was furnished, the greatest production per day occurred when the consistency was 3%, and at the same consistency, the power consumed per ton of stock was least. If the consistency could be increased without reducing the speed of travel, and without increasing the power consumed proportionately, then the efficiency of this beater would be increased; or if the speed of travel could be increased without reducing the consistency, and without increasing the power consumed proportionately, then the efficiency of this beater would be increased. To do either would require changes in the design of the beater.

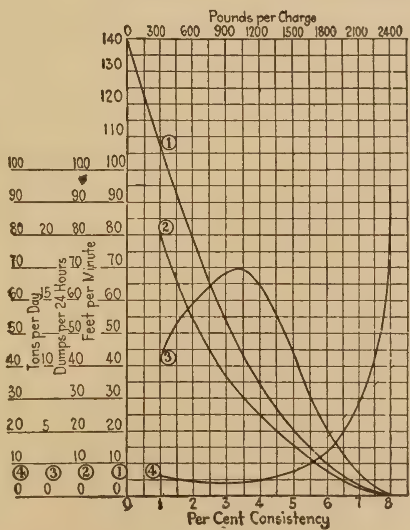


Fig. 27.

78. The Viscosity Theory.—Experiments leading to the two foregoing theories have rested on the observed behavior of the

stock in going over the paper machine, and on the quality of the final paper. The subject has been treated in this country from a radically different angle. Thus, the first step of the series of tests was to develop means by which small pulp sheets could be formed under exactly standard conditions; so that they could be tested in all of the known ways separately, and conclusions could be drawn, independently of the manner in which the beaten stock might be treated in the refiner or on the paper machine. Moreover, such sheets were made from samples of the stock taken from the beater at regular intervals during the beating; and, in this way, charts were constructed showing the changes made in bursting strength, folding strength, sizing, shrinkage, and bulk, *separately*, as related to the setting of the roll, the pressure exerted by the roll on the bed-plate, the speed of circulation, consistency, and power consumed. It was found, for example, that a given amount of beating, applied to a given stock at a given consistency, often increases bursting strength, but decreases folding strength, as compared with a lesser amount of beating; and the question arises, which manner of beating should be considered more effective. In other words, it is in many cases misleading to assert that a certain roll action, or a certain number of passages under the roll, constitute a given amount of beating; for such an assumption does not take into consideration all the facts. The amount of beating must be judged primarily by the particular qualities in the final paper that it is desired to have; then that manner of beating best adapted to enhance those qualities is the one to be selected.

The tests were carried out in the way described for seven years under a great variety of conditions, for the purpose of finding some method of so directing the beating of stock as to be able to repeat in a succeeding furnish of stock the same qualities, at the end of the beating, that had been produced in a previous furnish of stock. The key to the problem was finally found when it was discovered that changes in frictional resistance in the stock have a direct bearing on the qualities of the final paper. With a given furnish and a given consistency, the action of the beater results in changes in the *surface* friction, and *internal* friction, of the stock. If these changes are made in the same way and to the same degree in one furnish after another, the final paper will possess the same qualities.

CONTROL OF BEATING

79. Two Ways of Controlling.—There are two ways of attacking the problem of control of beating: one way is to control the setting of the roll directly; the other way is to control the setting of the roll through measurement of the results of roll action on the stock. By the first method, the control of the roll directly, either the distance between the roll and the bed-plate, or else the weight exerted by the roll on the bed-plate, can be the factor chosen for control. But it must be clear at the outset, and always kept in mind, that if a beaterman is to be required to set the roll at the same distance above the bed-plate every time, or if he is to be required to set it upon the bed-plate with a given pressure each time, he must have some method of getting the beater furnished to the same depth and with stock of the same density; otherwise, these mechanical elements of control cannot be expected to give uniform results.

When no special instructions or apparatus are given to the beaterman, the condition of the stock and the manipulation of the roll are determined by him by the feel of the stock, or by the use of a small bowl or copper dipper, of about 2-quart capacity. Into this bowl, a small portion of stock is mixed with a relatively large quantity of water, and the appearance of the fibers and the absence of small clots or bunches of fibers are an assistance in judging the condition of the stock in the beater. Often two vessels are used, and the stock is observed as it passes over the edge of one to the other. Also refer to description of blue glass test in *Manufacture of Mechanical Pulp*, Section 3, Vol. III.

80. Control of Density.—A prime requirement of control of beating, then, is control of density (consistency) of the furnish, that is, of the percentage of paper-making material in the stock. In one or two mills where this problem has received careful attention, methods have been worked out for weighing the pulp into the beater and measuring in the water. But pulp comes to the mill in many forms and at different moisture contents; and to be weighed correctly, it must be reduced to the same moisture basis. A very effective device for doing this is a small centrifuge, such as is used by laundries for a preliminary drying of clothing. It has been found by experiment that a sample of wet stock, properly treated in a centrifuge, will always come out at a uniform moisture content. In order to compute the weight at

any moisture content, it is only necessary to know what per cent of moisture exists; therefore, the sample that is treated in the centrifuge gives the basis for all calculations regarding moisture; it gives the beater-room management data for computing exactly what quantities of the various stocks are to be weighed in, to fill a given furnish, and what quantities of water to add. Until this method was devised, the problem of furnishing definite amounts of stock from the drainer, for example, has been almost beyond precise control.

81. A Consistency Regulator.—A successful type of consistency regulator widely used on wood pulps is shown in Fig. 28. Stuff enters the constant-head box *N*, in the bottom of which is a round

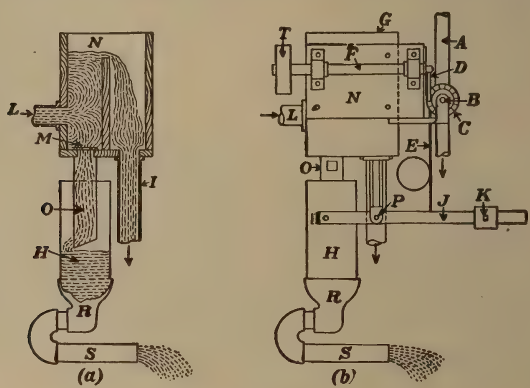


FIG. 28.

orifice *M* in a brass plate. A constant head is maintained by admitting more stuff through pipe *L* (pumped at a constant rate from the pulp tank or Jordan chest) than can pass through the orifice *M*, the excess overflowing the baffle into pipe *I*, which conducts it back to the chest. That part of the stuff that flows through orifice *M* passes through pipe *O* into the variable level or weighing chamber *H*, which is mounted on a scale beam *J* that balances on knife-edge bearings at *P*. The counterweight *K* may be moved along the other arm of the beam as in any weighing machine, and is used to balance *H* and its contents.

82. Now it is well-known that the friction of stuff flowing in pipes varies with changes in consistency; also, if a relatively constant volume of stuff is to pass through a pipe of given size, it will require a greater head (or pressure) to maintain the same

flow when the consistency of the stuff is increased. This fact is made use of in the following manner:

Through a small bypass, taken off from the main stuff pipe as close as convenient to the stuff pump, sufficient stuff is continuously drawn to maintain an overflow in the head box *N* of the regulator, thus maintaining a constant head on the orifice *M*, and producing a constant flow in the pipe *O*. Since this orifice offers a minimum of frictional resistance to the passage of the stuff, the amount discharged through it to the variable-level chamber *H* beneath it, will vary but little with changes in consistency. In passing from the variable-level chamber *H*, however, the stuff meets with considerable frictional resistance, which is governed by the reducing elbow *R* and by the size and length of the goose-neck outlet pipe *S*, with the result that the level in *H* rises a sufficient amount to overcome the resistance of the reducing elbow *R* and pipe *S*, and maintains the flow. Thus, when the consistency of the stuff increases, the level in chamber *H* rises; and when the consistency decreases, the level in chamber *H* falls.

A water-supply pipe *A* is connected to the inlet of the stuff pump (which supplies stuff to be regulated) by means of a gate valve, the stem of which is connected to a screw *B* passing through a double-faced ratchet wheel *C*. A pawl *D* is provided for rotating the ratchet wheel in either direction; a set of links *E* connects the scale beam *J* of the regulator and the pawl; a shaft *F* connects with an eccentric for operating the pawl; and a safety stop disengages the pawl when the valve is wide open or shut.

83. Stock of a given kind at a given consistency will fill weighing chamber *H* to a definite height; that is, where enough head is created above goose-neck pipe *S* to cause a rate of flow equal to the flow through orifice *M*. Thus, a definite weight of stock plus metal is established for any desired consistency of stock; and this weight corresponds to such setting of counterweight *K* as will balance it. The counterweight *K* is set to balance the weight of the chamber *H* and its contents at the desired consistency, and when *K* and *H* are in balance, pawl *D* will not engage with either side of the ratchet. If the consistency of the stuff increases, the additional frictional resistance will cause the stuff to back up in chamber *H*, increasing the weight of the stuff in the chamber (since the level of the stuff in the chamber rises); this brings down that end of the scale beam to which chamber *H*

is attached, and causes the other end, with the counterweight, to rise; this movement is transmitted by the links E, which cause the pawl D to engage with the ratchet wheel C, and rotates the ratchet wheel. Since the ratchet wheel cannot move sideways, it will cause the screw B (to which it is threaded) to back out and open the water-inlet valve until sufficient water is added at the pump to reduce the total volume of stuff passing through the pump to the proper consistency. When this occurs, the scale beam again becomes horizontal, the pawl comes to neutral position, engaging neither side of the ratchet, and the water valve remains open the necessary amount. If, now, the stuff becomes too thin and less water is required, an opposite movement (due to the same causes as just described) will close the valve the necessary amount. A safety stop disengages the pawl when the limits of the valve travel are reached.

If sufficient care be taken to insure proper operating conditions, stuff can be controlled with this apparatus with a maximum relative variation of 5% over or under the desired consistency. The same apparatus may be attached to the pump and pipe system delivering any kind of stuff from the Jordan chest, through the constant-head regulating box to the Jordan, or from the machine chest to the paper machine.

84. Instead of separate constant-flow regulating boxes delivering stuff of uniform density to the mixing tank, there may be used an automatic proportioning device recently developed. This consists essentially of the required number of constant-level stuff chambers, from which stuff is delivered through flat openings, which are provided with a slide valve that opens one part as it closes the other. With the proper proportions of pulp in constant quantity at uniform consistency thus insured, it is possible to add color, size, clay, etc., in solution or suspension in just the right amount. For a description of this apparatus, see Vol. V, Section 1, Part 1.

85. Consistency Indicator.—The beater drag, Fig. 29, gives control of the consistency of the furnish; accomplished by bringing the arrow L to a prescribed point and, at the same time, having the beater filled to exactly the same depth. This result is effected most readily if one kind of stock is coming to the beaters in slush form; for, in that case, a steady stream of slush stock may be run in while water is taken out by means of a cylinder washer,

thus maintaining the proper depth in the tub, until the arrow stands at the right point on the scale. This method is sufficiently accurate in careful hands to control the consistency of the furnish within a relative variation of 2%.

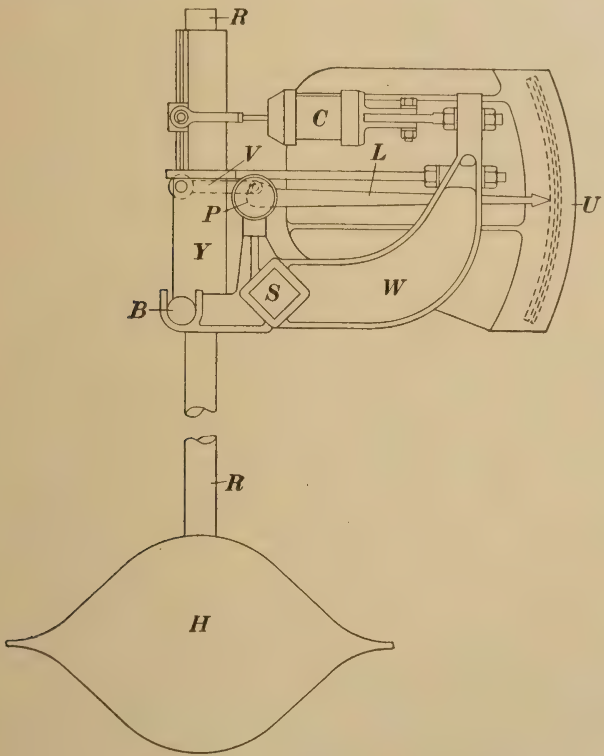


FIG. 29.

86. Controlling Consistency at the Jordan.—In mills where no method has been adopted for the control of the density factor, it is customary to compensate for the fluctuation by adding water at the Jordan, adding more when the stock seems thick and less when it seems thin. However, since density is the starting point in the control of beating, the better plan is to maintain uniform consistency, when once obtained, from the beaters to the paper machine; this may be done by adding the proper amount of water in dumping, so that the consistency of the stock in the chest is kept uniform. A very satisfactory device for this purpose is the **recording liquid-level gauge,** since paper pulps are of prac-

tically the same weight as water. The diaphragm of the recording liquid-level gauge is placed well down in the chest; when it shows that the surface of the stuff in the chest has fallen to a certain level, the next beater is dumped, and the proper amount of water is used in dumping to bring the surface of the stuff up to a higher prescribed level. If, then, this predetermined amount of dumping water is made such that the resulting consistency in the Jordan chest is right for passing through the Jordan, no water has to be added at the Jordan, and the uniformity of consistency once established in the beater is maintained up to the paper machine. It has been found that this factor can be so well controlled that ream weights on the machine almost maintain themselves.

87. Control by Setting of Roll.—Returning now to the plan of controlling by changing the setting of the beater roll, the same results in the stock will not be produced by the same position of the roll or the same roll pressure, as has already been shown, unless the consistency is the same. But even with the consistency uniform, the quality of the stock coming to the beater varies. Some stocks require drastic roll action and some less drastic action, for uniform results in the paper. That which requires less treatment will get over-treated, by being subjected to the same roll setting, as compared with that which requires more treatment, and the independent means of governing the roll setting would thus fail to compensate. This method has been the subject of many careful experiments, in which both of the mechanical methods of governing the roll setting were employed. To obtain control of beating, therefore, it is necessary to develop some measuring unit to express the *result* of beater treatment on the stock.

88. Watt-Meter Control.—It has been stated that a large part of the power used in beating is consumed in circulating the stock; with any one beater, this power consumption will be constant for the same furnish and consistency. Any variation in the power consumed will then be caused by a change in the adjustment of the roll and its consequent pressure on the bedplate and effect on the stuff. Any changes in power consumption are immediately reflected in the reading of a wattmeter in circuit when only one beater is driven from a single electric motor. By using a reliable recording wattmeter, a curve is drawn that serves as a control and guide; and by duplicating

the curve, it is possible to duplicate beating conditions very closely, although for really accurate work, this method is probably not so dependable as some others, because of the elements of beating action which it leaves out of account.

89. The Beater Drag.—The theory of beating control will be discussed later; but it may here be stated that the roll counterpoise and the Wallace-Masson beater-roll regulator both operate to govern mechanically the setting of the roll, whereas the beater drag, shown in Fig. 29, measures the changes produced in the stock by beating.

Referring to Fig. 29, a square shaft S spans the channel of the beater opposite that in which the roll runs; it is supported on guides at its ends, which are arranged to lift and fall on stanchions, through a distance sufficient to permit the drag to be lifted up out of the tub during the dumping and furnishing operations. Fastened to the shaft S and held rigid by it is a frame W, which, in turn, carries a bearing B, by means of which an oval rod R, free to swing slightly, is hung vertically. In Fig. 29, the stock is supposed to be traveling from left to right. Rod R is anchored back to frame W through a coiled spring, enclosed in spring case C. There is a pivot bearing at P, which carries a light-weight bell-crank lever L, on the outer end of which is an arrowhead, which runs up and down across scale U. The inner end is connected by link V to the oval-rod bearing bracket Y. At the lower end of rod R, is a smooth body or bulb H of proper shape, perhaps lemon-shaped. As the stock thickens and creates a greater pull against this bulb, the rod R swings, which motion is conveyed through V to L; this causes L to rotate about P, and thus deflects the arrowhead upward; but when the stock is made thinner, the pull diminishes, and the arrowhead falls. Each position of the arrowhead is recorded automatically by suitable clockwork mechanism.

As the beating progresses, a curve is automatically drawn on a chart, which represents the varying degree of pull exerted by the stock against the bulb H. If the stock is furnished to a fixed depth in the tub at the beginning of the run, and the arrowhead is brought to a predetermined point on the scale, the density of the furnish is thereby made uniform. The combination of a fixed furnishing point and a given curve on the record, composes the basis for instructions as to the beating;

and the record of the recorder provides the history of every run, which may be compared with the instructions issued.

90. Experiments extending over five years, made both in the laboratory and under actual mill conditions, resulted in establishing the following principle: The mass of stock in the beater is treated as a fluid mass, such as molasses; and the friction of this fluid mass on bodies that are made to move through it is measured, coupled with the friction of this mass when rubbing on itself. In other words, both the internal and surface frictions of the mass are measured. As the beating progresses, these frictional factors change. A curve may be drawn by the automatic recording attachment.

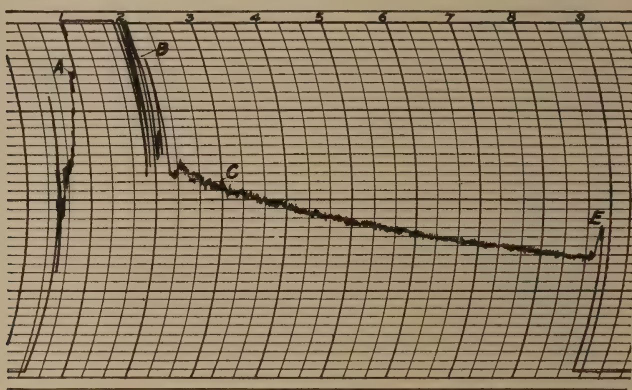


FIG. 30.

The principle is, then, that if this curve is reproduced each time that the same furnish is made in the same beater, the quality of the resulting paper will be uniform.

To repeat this curve with the same furnish, instructions are given in the form of a table of readings, one reading for each period of time, say 15 or 20 minutes, throughout the run; the beaterman adjusts his roll as the run proceeds, in such a way as to follow out the readings as set, and thus duplicate the curve. Each different beater of the set on the same furnish requires a different curve, because beaters do not have the same action on the stock, even when in the same condition of repair or wear.

Although this principle has not been applied in daily practice to other than short-fibered stocks, a sufficient number of experiments have been made to indicate that it has universal applica-

tion. Long-fibered stocks require, however, a different form of measuring device—one that will avoid snagging. But the relationship between the frictional resistances and the quality of the stock is apparently a universal principle, in connection with the beating of stock for paper.

91. Some mills report the successful application of a mechanical-motion recording instrument to beater operation. A time chart, driven by clockwork, is graduated in inches or points, and on it is drawn a curve by an accurately moved pen, showing the settings of the beater roll. For one particular beater and grade of stock, definite directions for roll settings can be given and checked.

92. Control by Measurement of Freeness.—The freeness of stock prepared for making paper decreases with the increased degree of hydration of the fiber. The progress of this action may be followed and measured relatively by determining the rate at which water will drain from the stock at standard temperature and consistency. The effect of temperature is not always fully appreciated; it is, however, very important, since water at its boiling point drains about five times as fast as water at the freezing point. It is also obvious that results can be compared only when referred to stock of the same consistency.

93. The desirability of having a satisfactory method for judging beater performances is self-evident. Beaters are often found in use long after the bed-plates and knives have become distorted and ineffective, and there is considerable uncertainty in deciding just how far off the bed-plate to set the roll in order to secure a desired degree of beating. Recent experimental work has shown that the freeness tester is well adapted to give exact information regarding the condition of the knives and bed-plates, and also how much beating may be expected with a given roll setting. Davis[1] shows how such a beater test may be conducted, first outlining a method for operating the freeness tester, and indicating the use of two correction charts.

The apparatus,[2] Fig. 31, consists of four units, of which only the tester is shown: a motor-driven centrifuge, a motor-driven stirrer, an electric heating coil that fits into the centrifuge, and

[1] Davis, D. S., *Pulp and Paper Magazine*, Aug. 26, 1926, and July 5, 1928.
[2] The freeness tester described in Art. **56** of the Section on *Refining and Testing of Pulp*, Vol. III, can also be used here, but the curves will differ.

the tester proper. At the upper part of the tester is a cup C with a screen bottom, against which is fitted a flat plate or foot-valve V. One liter of a pulp suspension, of about 0.4 per cent consistency, is poured into the cup. On tripping the valve, the water drains from the pulp through the screen into the conical chamber D. At the bottom of this chamber are two outlets, one B leading to a graduate, and the other O conducting the water to waste. The half-inch measuring orifice B is slightly the higher, so that as the level of the water in the conical chamber drops, the flow into the graduate is cut off sharply. The water that continues to drain from the fibers runs out through the lower outlet. The volume of water, in cubic centimeters, that passes to the graduate, is called the **freeness number,** which is designated by F.

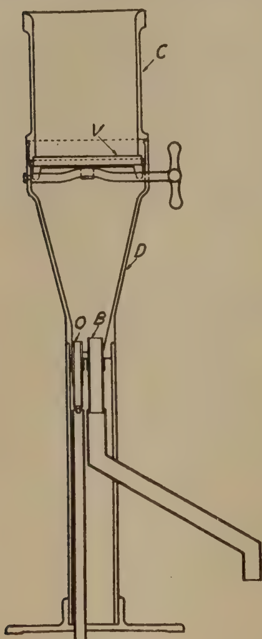


Fig. 31.

Sufficient stock, or somewhat more than 24 grams bone-dry weight, is made up to 6 liters in a pail and is agitated by the motor-driven stirrer; 500 c.c. is withdrawn and is brought to the bone-dry condition in the centrifuge, with the aid of the heating coil. The bone-dry lap is removed, weighed rapidly, reheated, and re-weighed, and the consistency of the stock is calculated. If the value thus found does not lie between 0.35 and 0.45, the stock should be diluted to a consistency within that range. One liter of the suspension is poured into the cup of the tester, and the freeness is read from the graduate, at which time the temperature of the effluent water should be taken.

All freeness values should be corrected to a consistency of 0.400 per cent and a temperature of 20°C. These corrections may be made by use of Figs. 31*a* and 31*b*.[1] Thus, given the freeness of a stock as 500, determined at a consistency of 0.36% and a temperature of 24°C., what is the freeness at 0.400% and 20°C? In Fig. 31*a*, follow the 500 line horizontally to its inter-

[1] These charts apply only to the Williams apparatus used by Davis, but similar curves can be prepared for other instruments.

section with the 0.360% line; then interpolate the freeness at 0.400% and 24°C., along the slant lines, to be 476, i.e., 0.476%. In Fig. 31*b*, follow the 24° line vertically to a freeness of 476 and

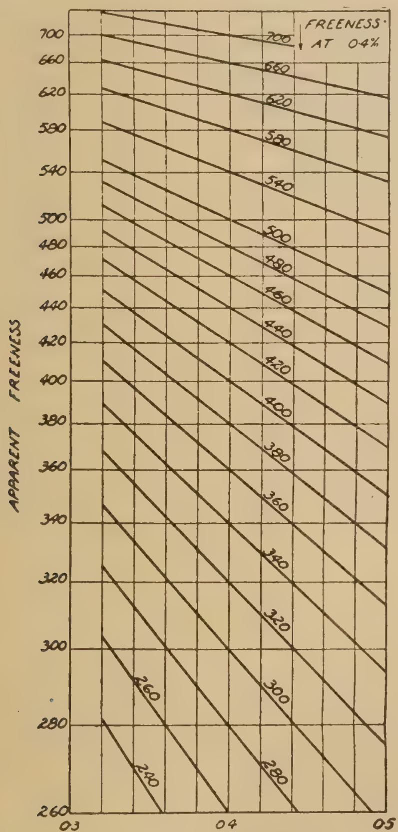


FIG. 31*a*.

read the freeness at 20° to be 450, i.e., 0.450, along the slant lines. If desired, both corrections may be dispensed with by adjusting the consistency of the stock in the pail to just 0.400% and heating or cooling the stock to just 20°C. Considerable time is saved, however, by the use of the charts.

94. The rate of decrease of freeness during beating may be considered a measure of beater performance. A sample of stock is needed before beating has begun, and one just before the beater is dumped, the time interval being measured; the first sample

should be taken after thorough mixing, but before much beating has been done. Samples should be taken at several points in the beater—some near the midfeather, some near the outer wall, and some in the center—and they should be united. The final samples, after a definite time has elapsed, should be taken in a similar manner at several points.

The freeness values of the two sets of samples are then determined, and their difference is plotted against the time of beating, as in Fig. 31*c*, the furnish here being sulphite pulp and book stock. Tests on several charges are made with the same roll setting, and the best line is drawn through the plotted points. The slope of this line, in units per hour, is the rate of change of freeness, and it may be considered as a satisfactory measure of the performance of the beater. In this instance, the rate of change was 68 points for the first $2\frac{1}{2}$ hours, after which it decreased.

Once the rates of change of freeness are determined, it is easy to decide how long to beat a given stock, and an economic balance could then be made to determine at what rate of change it would be advisable to replace the knives and bed-plate. The performance of Jordan engines may be judged by similar tests.

QUESTIONS

(1) Explain the operation of the roll counterpoise. What advantage is taken of this principle in the Wallace-Masson attachment?

(2) Describe one type of continuous beater attachment

(3) How does the beaterman know how close the roll is to the bed-plate?

(4) What differences in beating would produce a soft paper or a hard, rattly paper from the same furnish of stock?

(5) (*a*) Why is loading used in some papers? (*b*) Should loading be considered adulteration?

(6) What parts of the beaterman's duties could be served better if he had some knowledge of chemistry?

(7) In what way would you consider the microscope helpful in controlling the beating operation?

(8) How is freeness (or slowness) measured, and what does the result obtained indicate?

PAPERBOARD

95. General.—Paperboard includes a wide range of products, which are made on single- or multi-cylinder machines, and are

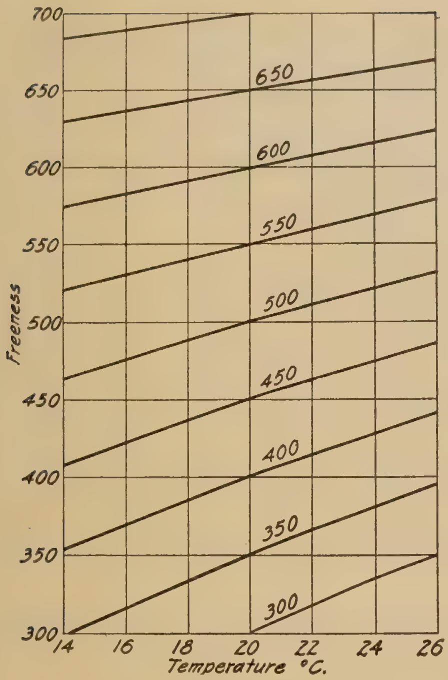


FIG. 31b.

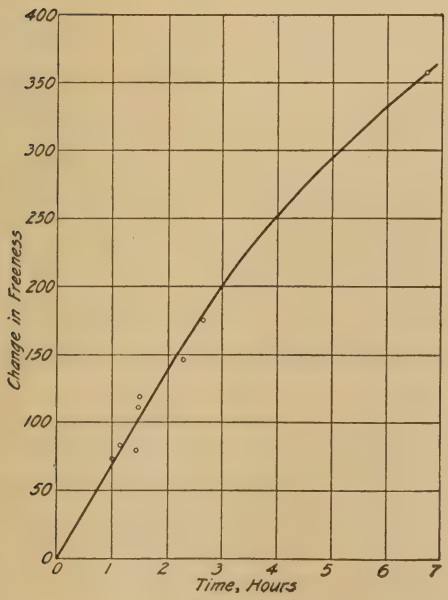


FIG. 31c.

composed of from one to three different stocks. They may be classified as follows:

(1) Chipboard—"plain chip."
(2) Set-up box-boards.
(3) Straw paper for corrugating—0.009 in. straw.
(4) Heavy strawboards.
(5) Test liners—container board.
(6) Folding box-boards.
(7) Miscellaneous boards—binders, fiber, press, trunk, tag, building, etc., as well as saturating felt, and other specialities.

Chipboard is largely used for set-up box manufacture; it is frequently lined with litho, news, book, and other papers, as in shoe boxes. Chipboard consists entirely of mixed papers.

Set-up box-boards comprise those possessing stiffness and which do not require bending qualities. Strawboard is a set-up grade. Set-up boards consist largely of groundwood, old newspapers, and mixed papers, and may be composed of one to three stocks.

Test liner, a kind of folding box-board, is used for solid or corrugated shipping container-board; it must possess great bursting strength, waterproofness, evenness of weight and caliper, and a good printing surface.

Folding box-boards are used in folding boxes, which are shipped flat and largely used for drugs, cereals, etc. They have one or both sides of high-grade stocks that contain chemical pulps for good bending qualities, with the filler, or back, of newspapers, mixed papers, etc. These boards must possess good color, sizing, formation, printing or lithographing surface, bending qualities, and cleanliness; in fact, some high grades are being used in place of clay-coated boards.

96. Waste Papers.—The various grades and the classification of waste papers are covered in Section 2, *Treatment of Waste Papers.*

A few mills dust and sort their shipments of mixed papers. The dusted stock is passed to conveyor belts, where strings, rags, bricks, etc., together with higher grades of papers, such as kraft, bond, etc., are removed; the latter are baled and sold.

It is undoubtedly true that dusting will remove the fine dirt better than any subsequent dilution and riffling, since the paper is dry and dirt does not tend to adhere to it. However, the low

price levels of paperboards, and the more general practice of pre-sorting and removal of higher grades by the dealers, do not allow this operation to be generally profitable. Moreover, this practice necessitates that the mill enter the waste-paper-stock business, and this has not proved successful. In general, mills prefer to purchase on specification and carefully to inspect shipments.

A sufficiently large, well laid out paper-stock and pulp warehouse is necessary for the modern board mill, if labor costs are to be kept at a minimum. These are frequently equipped with traveling cranes, to permit easy handling of bales to the breaker beaters, usually located there. For the mill of two or more machines, a weighmaster, in charge of truckers and stock, is essential; he also inspects the quality of the shipments. The use of many different stocks, and the handling of clean and dirty stocks together, make close control essential, since the items of stock, and the proper control of beater-room activities, are half of successful paperboard manufacture.

It is advisable to open bales and sort out as much refuse as possible from mixed papers at the breaker beaters or continuous beaters.

De-inking is not practiced on mixed papers and news; and the use of breaker beaters and continuous beaters has made the use of shredders unnecessary. The gray color obtained from news or mixed papers suffices for the purposes for which these qualities of boards are employed. A few mills practice de-inking of certain stocks for use in liner stock.

97. De-fibering and Beating.—When more than one kind of stock is used in a sheet, the beater and Jordan systems are arranged to handle two or three kinds of stock simultaneously. A two-way system has two sets of beaters, beater chests, stuff boxes, Jordans, machine chests, and connecting pumps; a three-way system has three sets. In such cases, the equipment is so piped as to be interconnecting. For example, in a three-way system, as shown in Fig. 32, when running on a two-stock board order, the system that would usually be on the third stock would operate on the same stock as the second system.

Chipboard can be made in a one-way mill; set-up box-board mills are either two- or three-way; folding box-board are usually three-way.

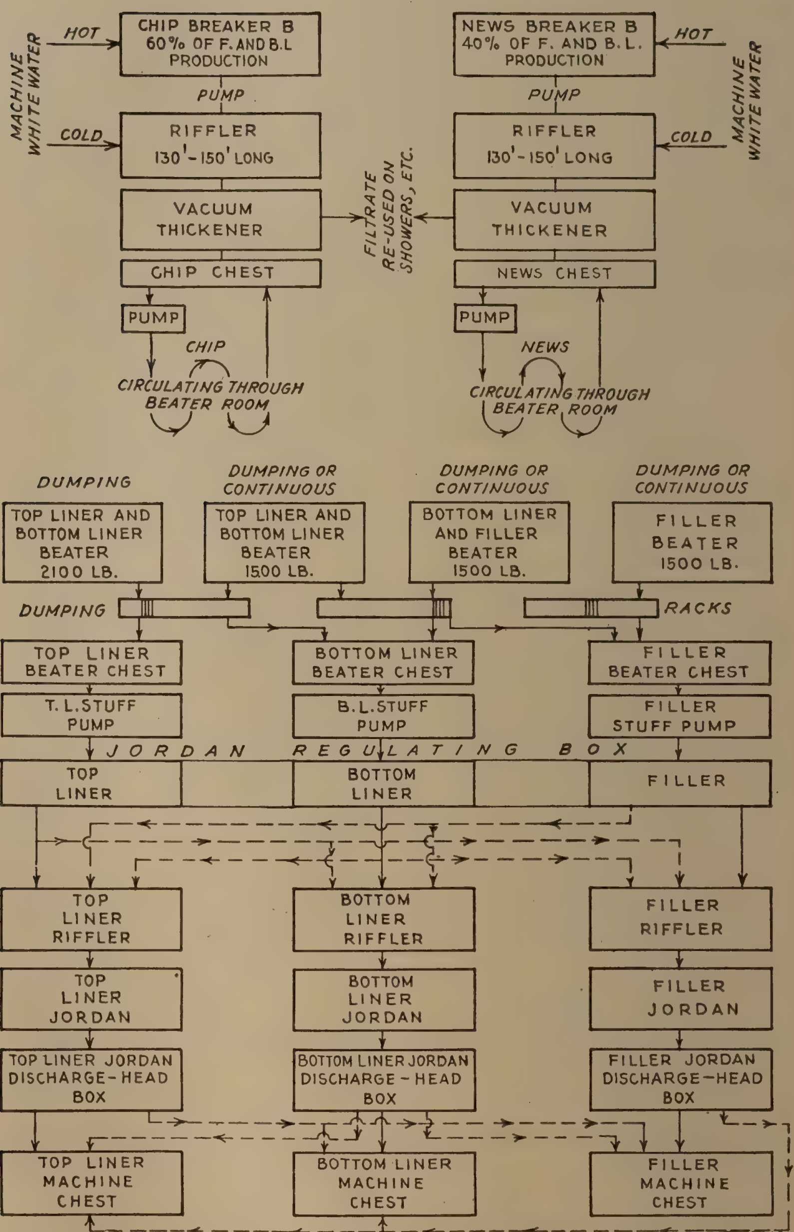

MACHINE WHITE WATER
HOT
COLD
CHIP BREAKER B 60% OF F. AND B.L PRODUCTION
PUMP
RIFFLER 130'-150' LONG
VACUUM THICKENER
CHIP CHEST
PUMP
CHIP
CIRCULATING THROUGH BEATER ROOM
FILTRATE RE-USED ON SHOWERS, ETC.
NEWS BREAKER B 40% OF F. AND B.L. PRODUCTION
HOT
COLD
MACHINE WHITE WATER
PUMP
RIFFLER 130'-150' LONG
VACUUM THICKENER
NEWS CHEST
PUMP
NEWS
CIRCULATING THROUGH BEATER ROOM
DUMPING
TOP LINER AND BOTTOM LINER BEATER 2100 LB.
DUMPING OR CONTINUOUS
TOP LINER AND BOTTOM LINER BEATER 1500 LB.
DUMPING OR CONTINUOUS
BOTTOM LINER AND FILLER BEATER 1500 LB.
DUMPING OR CONTINUOUS
FILLER BEATER 1500 LB.
DUMPING
RACKS
TOP LINER BEATER CHEST
BOTTOM LINER BEATER CHEST
FILLER BEATER CHEST
T. L. STUFF PUMP
B. L. STUFF PUMP
FILLER STUFF PUMP
JORDAN REGULATING BOX
TOP LINER
BOTTOM LINER
FILLER
TOP LINER RIFFLER
BOTTOM LINER RIFFLER
FILLER RIFFLER
TOP LINER JORDAN
BOTTOM LINER JORDAN
FILLER JORDAN
TOP LINER JORDAN DISCHARGE-HEAD BOX
BOTTOM LINER JORDAN DISCHARGE-HEAD BOX
FILLER JORDAN DISCHARGE-HEAD BOX
TOP LINER MACHINE CHEST
BOTTOM LINER MACHINE CHEST
FILLER MACHINE CHEST

Fig. 32.

The outside face or faces (layers) are called **liners,** each being made on one or two cylinders of the board machine. This stock is prepared in beaters of the Holland type, preferably, high speed. Since there are frequent machine changes, it is not customary or feasible previously to de-fiber the liner stock.

When one liner only is made, the rest of the board is called the **back;** when both sides are printing surfaces (liners), the inside of the board is called the **filler.** Stock for filler and back—largely mixed papers and news—is now de-fibered to a great extent, either in breaker beaters or with high-speed beaters equipped with continuous beating attachments or extractors. The object of both is the same—to allow stock that has become sufficiently defibered and reduced to pass out of the beater continuously, fresh stock and hot make-up water being fed constantly. Since mixed papers and news have already been sufficiently beaten once, they require only to be de-fibered.

Several continuous beating attachments, or extractors, have previously been described. Another extractor consists of a hollow vertical roll at the end of the midfeather; it is made of perforated metal. Still another scheme, which is working very satisfactorily on saturating felt, is to extract the stock thrown over the roll through a narrow slot into a chute, which discharges into the following beater, and so on, the last beater in the series having a small vertical standpipe in the tub, down which the stock continually flows.

In some cases, continuous beaters supply chests that supply secondary beaters, as where other stocks must be mixed; in other cases, filler stock passes from the continuous beaters direct to the Jordans. The system of preparing mixed papers or news in Holland beaters, and dumping direct to the beater chests, is rapidly becoming obsolete. As above indicated, the roll never touches the bedplate, as no real beating is necessary.

If a breaker-beater system is not used, it is imperative to remove as much refuse and rags as possible before the stock reaches the chests. This is done by rag catchers installed in the beaters; or, better, by dumping or continuously extracting into dumping racks, which are simply flat gratings, composed of bars about 1 in. apart, connecting with the chests below. Interconnection between chests and beaters is conveniently made by suitable gates and piping from these racks, one rack serving two beaters and allowing stock from either beater to be dropped into

either of two chests, as filler or back liner. The rags and sticks collected on the bars are forked out, the stock being washed through a hose.

Although preferable to using dumping beaters alone, as regards the extraction of refuse, they are not as efficient as a breaker-beater system, since the stock is too thick for good settling. Rifflers are sometimes installed between the Jordans and the stuff box. If provided with frequent rows of pins, with burlap bottoms, and if frequently cleaned, these remove much refuse; but Jordan consistency is not the best riffling consistency—the stock is too thick.

98. A Breaker-Beater System.—The Shartle breaker-beater system affords a very efficient means of preparing mixed papers and news: it effects large savings in labor, power, and maintenance; and if it be properly installed and operated, it gives quite clean stock. In this system, the bales,—split in two or three wads, or opened and sorted as fed,—are dropped into a large concrete tub, placed at floor level. White water, at about 165°F., is added continuously for make up, the stock being also added continuously, as in the case of continuous beaters. The roll has 18 bars, 10 in. wide by 1 in. thick. There is no bed plate, the roll being 6 to 8 in. from the bottom of the tub. A hollow midfeather supports one of the roll-shaft bearings, which are rigid, the shaft ending at this bearing.

A rag catcher is used to remove the rags at regular intervals, the stock, when sufficiently de-fibered, passing through $\frac{3}{4}$-in. holes in the back-fall and into the pump seal box. This pump supplies the rifflers, where the stock is diluted to 1 per cent bone-dry consistency, or less, with further white water, the riffled stock being thickened on thickeners of the decker type. The thickeners discharge into a stuff chest, which supplies the beaters. With riffler stock at the above consistency, and with frequent cleaning, the rifflers will remove the greater part of the small refuse. There are several modifications of this system.

Another system uses rotary boilers. The mixed papers, after sorting and dusting, are cooked for 2 to 3 hours at 30 to 40 lb. steam pressure. The cooked stock is then kept agitated, in a swirling movement, with white water in a settling tank. Much heavy refuse settles out here, the floating materials, as wood and cork, being skimmed off. The stock then flows to rifflers and

thickeners, as in the Shartle system. The rifflers are provided with spikes, which serve as string catchers.

When dumped, the papers are thoroughly de-fibered, and they require very little jordaning. Because of the dry dusting, the dirt removal is somewhat better than in the breaker-beater system. The stock is liable to give a "punky" sheet, and is more subject to blowing on the machine.

99. Liner Stock: Water Sizing.—The stock for printing surfaces of boards is largely made of the white grades of waste papers, such as blank news, soft white shavings, envelope clippings, manilas, etc. Sulphite, soda, and groundwood pulp are used in varying amounts, together with clay or asbestine filler, starch or silicate for stiffener, size, alum, and color. These stocks are beaten—brushing rather firmly—for from 1 to 3 hours, depending on beater capacity, hardness of finish, and freeness from fuzz, etc.

Liner stock is frequently hard sized, as for lithograph work. To effect this, the make-up water is added at about 140°F. After furnishing, the temperature will be around 125°, and after 30 min. brushing, it will be down to about 120°, which is suitable for good sizing. The penetration of printer's inks, which have oil bases, is more a function of the closeness of formation than of sizing, though this helps to give a well knitted sheet and to prevent fuzz.

Filler and back are not usually well sized, although alum is necessary in any case.

A temperature of 165°F. in the water is necessary in de-fibering filler stock, in order to dissolve chewing gum, paraffine, etc., so they will not show in the sheet or clog the cylinder faces too much. Make-up water is heated in a heater that much resembles a return tubular boiler. The steam may be passed through the tubes, with the water around them, or the reverse of this. In the latter case, it is necessary to use the filtrate from a save-all, which allows not more than 0.75 lb. per 1000 gal. of solids in the filtrate, as from the vacuum-drum type, in order to prevent fouling of the tubes.

Test-liner board must resist water penetration for 3 hours. The sheet must be hard sized, and free from sand holes, etc. The *penescope* offords a quick method of testing, and it gives in 30 min. the equivalent of 3 hours test in paper cones.

100. Jordaning.—Filler stock from the secondary beaters contains many unde-fibered pieces of paper, small threads, sticks, etc. The Jordan is relied upon to reduce these pieces, and to shorten the fibers to such condition that 0.030- to 0.035-cut, flat screen plates will pass stock without lumps, etc. showing in the sheet.

Liner stock, since it must provide the bending quality, is not jordaned so heavily, although in both liner and filler, the freeness necessary is varied, depending on the thickness of the sheet.

REFINING

REFINING ENGINES

THE JORDAN

101. Importance.—The refining engine, as shown at *H* in Fig. 20, is not a necessary part of the beating equipment; but, because of its usefulness as a means of preparing a stock that will form well on the paper machine, it is found in all mills of large production, and in most fine mills; while in mills making a low grade of paper, it has surpassed in importance the beater itself. The most common type of refining engine is the Jordan, named after its inventor.

102. Description.—A typical design of a Jordan engine is shown in Fig. 32. The working parts are conical in shape; they consist of a shell *S*, within which a plug *R* revolves, and to which it fits. Plug *R* is rigidly attached to a shaft, which turns in three bearings *B*, and is driven (in the case of a belt drive) by pulley *P*. Many Jordan engines are now installed to be direct-driven by electric motor, in which case, the motor is placed in line with the shaft of the Jordan, and is direct-connected to it by means of a special coupling, which permits horizontal movement of the plug, toward or from the motor. In some designs of direct drive, motor, plug shaft, and plug move together.

The Jordan is adjusted to govern its action on the stock by moving the plug horizontally, thus bringing its surface nearer to or farther from the inside surface of the shell. This action is similar in effect to the adjustment of the beater, when the roll is moved toward, or from the bed-plate. In the case of the beater,

the surface of contact between the roll and bed-plate is very narrow—almost a line—while in the Jordan, the surface of contact is the entire inside surface of the shell. In the beater, the direction of movement of the roll during adjustment is at right angles to the axis of the roll; but in the Jordan, it is parallel to the axis of the plug. To effect this latter movement, the bearing shown at the large end of the cone is a thrust bearing, to enable it to withstand pressure action lengthwise along the shaft as well as to support the shaft from underneath. This thrust bearing is connected to a worm screw, which is fastened to the frame of the engine, and is operated by turning the hand wheel *H*. When the hand wheel is so turned that the plug, and the shaft to which it is keyed, move to the left, Fig. 33, the plug is

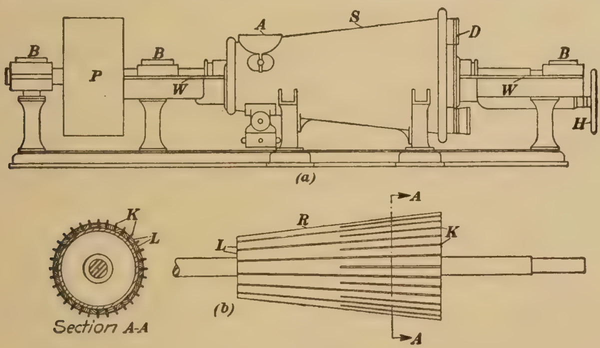


FIG. 33.

set harder into the shell. The bearing boxes are fitted to run in machined ways *W*, in the same manner as the tool stand on a lathe.

103. The necessity for the thrust bearing is due to the fact that the plug is conical instead of being cylindrical. Since the surface of the plug makes an angle with the axis instead of being parallel to it (as in the case of a cylinder), any pressure acting on the surface may be resolved into two components, one of which will act parallel to the axis and the other perpendicular to it. The force exerted by the first component is the one that is resisted by the thrust bearing. The larger the angle that an element of the cone makes with the axis the greater will be the horizontal thrust.

As has been stated, the beater is furnished and dumped alternately, a batch process; but the Jordan takes its supply from a chest, which is a supply reservoir, and runs continuously.

The stuff from the flow box enters at *A*, Fig. 33, at the small end of the cone, and is discharged at *D*, at the large end. Both *A* and *D* are machine finished, to receive flanged pipe connections. The rotation of the plug at a relatively high speed causes the stuff to swirl between it and the shell, and the result of this swirling is to cause the stuff to be thrown toward the large end of the shell by centrifugal force. The stuff passes through the Jordan in the form of a rather thin mixture, and it behaves very much like water. It is under considerably greater pressure at the large end of the cone, therefore, than at the small end, and the Jordan is consequently capable of throwing it up in the discharge pipe to a considerable height. The Jordan thus acts somewhat like a centrifugal pump. Both the Jordan and the beater employ the working parts to propel the stock, the latter by acting like a paddle wheel, and the former by acting like a centrifugal pump.

104. A view of the plug alone is shown at (*b*), Fig. 33. It is fitted with bars or knives *K*, which are set in slots, milled in the webs that support the roll (plug). These bars are firmly held in place by wooden strips *L*, wedged in between them when dry. The construction is like that of the beater roll, except that the Jordan plug is conical. The large end of the cone (plug) is fitted with more bars than the small end, because its higher peripheral speed produces correspondingly higher rate of wear.

The shell *S* is also fitted on the inside with bars similar to those of the plug. Evidently, some means must be adopted to prevent the bars of the plug from locking with those of the shell; this is usually accomplished by setting the shell filling so it slants, first one way and then the other, in herringbone style. Jordan engines, and other refiners, are sometimes arranged in series where more than one is provided for one paper machine. Less commonly they are placed in parallel.

105. Origin of the Jordan.—The Jordan refining engine is a development of an earlier machine patented by T. Kingsland, of Franklin, N. J., in 1856. The Kingsland engine was a flat disk, with blades or teeth on both sides, set on a shaft, run in contact with two stationary disks, one on each side, which were fitted with similar corrugations. It was in use in the mills of T. & R. Kingsland, and was said to have produced some of the finest book and "flat cap" on the New York market. The intention

of the inventor was to devise a continuous process of beating that would supplant the beater.

In 1858, the conical refining engine was patented by Joseph Jordan, a paper-mill superintendent, and Thomas Eustice, a resident of Hartford, Conn. Many of the original experiments leading to the perfection of the machine were carried out by Jordan at Cumberland Mills, Me., in a book-paper mill, operated by S. D. Warren & Company, and the work was much facilitated by the encouragement of John E. Warren. Jordan's work was another attempt to supplant the beater; but, although this was not accomplished, the work was so well done, nevertheless, that the Jordan refining engine has come down to the present day with no important modifications.

106. Caution.—If the refining engine is of the Jordan type, that is, conical, it must never be left running without a supply of water passing through it to cool it; for it will heat very rapidly when running dry, no matter how far out the plug is pulled. In operation, it is kept cool by the stuff.

SPECIAL TYPES OF REFINING ENGINES

107. The Pope Refiner.—Although the Jordan is, by far, the most common single type of refining engine, there are various modifications of it in use, none of which, however, gets very far from the principle of the Jordan

Proceeding on the general design of the Kingsland, which was a flat disk that revolved on a horizontal shaft, the Pope refiner develops a single face of contact between the disk and the stationary plate, instead of the double contact employed in the older Kingsland engine. Further, the Pope is run at an exceedingly high speed, and there is very little clearance between the disk and the plate. The setting of the disk against the plate is as positive as in the case of the Jordan, the object being to prevent any yielding when small bodies of material enter that are coarser than the distance between the disk and plate, and to maintain the fixed plate distance, thus reducing the size of such bodies to a practically uniform fineness. It was the intention of the inventor to bring foreign particles found in the stock to such fine dimensions that they could be incorporated in the final paper without detracting from its appearance.

108. The Claflin Refiner.—The Claflin refiner stands between the two extremes of Jordan and Pope refiners; it takes the form of a cone, with a wide angle, and it is, consequently, very short. The purpose of the Claflin is identical with that of the Pope, and its design is like a very short, stubby Jordan. Its plug and shell are filled in a manner similar to the Jordan. In practice, it is frequently set up in series, a number of separate machines taking the stuff, one after the other. This machine is illustrated in Section 8, Vol. III.

109. The Marshall Refiner.—The Marshall refiner embodies some of the features of both the Jordan and the Pope, or Kingsland; it is a machine of the same size and weight as the Jordan. At the large end of the cone, however, the shell is faced with an annular ring, the position of which is at right angles to the center line of the shaft; and the plug is provided with a similar annular ring, which takes the form of a shoulder or collar. Both of these rings are filled with bars or knives. The plug is set in hard against the shell, which brings this annular ring in contact also; and the stock, which is thrown from the small end of the cone to the large end, passes through this annular ring last, thus encountering more working surface than is provided in the Jordan.

110. The Wagg Jordan.—In the wearing down of the bars of the Jordan engine, it often happens that much of the knife edge of the bars becomes dulled. It can readily be seen that neither the plug nor the shell will wear out in straight lines. Owing to the different peripheral speeds at different cross sections of the cone, the knives tend to wear in spots; and the spots in which the wear has been slower will tend to hold the plug and shell apart at the points where the wear has been more rapid. This is the explanation of the "howl," which is heard, sometimes, for long distances from the mill. The result on the knives is that, where they are not in perfect contact, they erode under the scouring action of the stuff, and then become all the less effective. To obviate this, the Wagg filling was devised. This consists of bars set in pairs, instead of being equally spaced, the two bars of a pair being not more than the thickness of the steel apart. If the forward bar erodes, the follower bar, being protected from the scouring, keeps more nearly to its original condition.

111. The Jordan Drive.—The preferable drive for the Jordan is a direct-connected induction motor, because of the ease of control through the electric-power meter, and also because this type of drive tend to maintain alinement. A belt drive, on the contrary, tends to wear the bearings in the direction of the belt pull, which causes the plug to work harder against one side of the shell than against the other side. In the case of stoppage of power in the beater room, the beater rolls must all be raised and the Jordan plugs pulled out, so that when the power is again applied, it will not operate at first against a full load.

112. Conclusion.—The beaterman's duties do not end when the stuff he has prepared passes from the Jordan engine to the machine chest; his responsibility continues until the stock is made into a satisfactory sheet. This necessitates close cooperation between the beaterman and the machine tender; each ought to understand the work of the other. The refining engine, serving largely as a fitter of beaten stock for the paper machine, comes near to the machine-tender's sphere; in some mills the refiner is in the machine-tender's charge. Whatever the line of division, however, cooperation and harmony are the keys to success.

QUESTIONS

(1) Make a pencil sketch of a Jordan engine and tell how it works.

(2) Describe one type of refining engine other than the Jordan.

(3) Should the beater room and the paper-machine room be considered as two distinct, separate, and independent departments?

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BEATING AND REFINING

EXAMINATION QUESTIONS

(1) What is the purpose of beating?

(2) Name the principal parts of the modern Hollander.

(3) How is the batch system of operating beaters converted into continuous operation for the paper machine?

(4) Make a pencil sketch of a pulp mixer and explain how it works.

(5) (*a*) What should be the size of a stuff chest? (*b*) What are the principal requirements of a good stuff chest?

(6) If the stuff in a Jordan chest is of 3% consistency and its weight is taken as 62.5 lb. per cu. ft., at how many revolutions per minute must the crank shaft of a single-acting, simplex pump turn to throw 1 ton (2000 lb.) of bone-dry stock per hour, allowing 10% for leakage in the pump? The diameter of the pump cylinder is 8 in. and its stroke is 12 in. Ans. 63 r.p.m.

(7) (*a*) How can uniformity of consistency be obtained when furnishing beaters? (*b*) Of what benefit is it to secure this uniformity?

(8) What should be done with the beaters and Jordans in case of interruption of power?

(9) State the usual order of furnishing the beater.

(10) Define: (*a*) bed-plate; (*b*) back-fall; (*c*) lighter; (*d*) free stock; (*e*) slow stock; (*f*) hydration.

(11) Describe some changes in the fiber as the beating proceeds.

(12) Do you think any type of refiner that is described in this Section can perform all the functions of a beater? Explain your answer.

(13) A certain beater has a capacity of 420 cu. ft. (*a*) If filled with stuff at 5% consistency, how many pounds of bone-dry fiber

will it hold? (*b*) How many pounds of wet laps of pulp, 30% bone dry, must be used to fill this beater to the above consistency? (*c*) How many pounds of water must be added with the laps of pulp? Assume that both the stuff and the wet laps weigh 62.5 lb. per cu. ft.

Ans. $\begin{cases} (a)\ 1181.25 \text{ lb.} \\ (b)\ 3937.5 \text{ lb.} \\ (c)\ 22312.5 \text{ lb.} \end{cases}$

(14) In connection with paperboard, what is meant by: (*a*) liner? (*b*) back? (*c*) filler?

SECTION 4

LOADING AND ENGINE SIZING

(PART 1)

By Ross Campbell, B. S.

LOADING

FILLERS

1. Why Paper Contains Substances Other than Fiber.—Fiber is, of course, the chief constituent of all paper. If, however, fiber were the only substance entering into its composition, the usefulness of paper would be very much restricted, as the sheet would be soft, of a yellowish color, and could not be written on with a pen; printing ink would not "take well" on it. If the sheet were thin, it would be so transparent that words written or printed on one side of it could be read through the sheet. An example of paper made of especially pure fiber is filter paper. It is necessary, then, to add many other substances to the fiber to produce paper suited to the many uses to which it is put; and among these substances are *sizing*, *coloring*, and *fillers* or *loading*. (**Loading** properly means the adding of a filler, but the term is also applied to the substances added.) If a sheet were made in the same manner as the average book paper, but without adding a filler, it would be found to be more translucent; *i.e.*, the printed letter would show through, and it would not, as a rule, take fine line cuts as clearly as it would if a filler had been added. The principal features in connection with the use of fillers will be treated in this Section.

2. What Fillers Are and Why They are Used.—All **fillers** are mineral substances: they may be (*a*) a natural product, as talc, which is merely a particular kind of rock, properly ground and bolted (screened); or (*b*) a manufactured article, as crown filler. Many substances used as fillers are also used for coating paper and boards; this latter use is not considered in the Section.

Although it usually has the effect of making paper less costly, filler is not, in general, added to paper for the purpose of cheapening it; its primary purpose is to secure qualities not otherwise obtainable. The largest quantities of filler are probably used in book papers, where it is desired to produce an opaque sheet that has good ink-absorbing properties and a very smooth and even surface for taking half-tone cuts; in this case, the presence of filler improves the surface, especially when the paper is supercalendered. The filler occupies the spaces between the fibers, so that the whole surface gets approximately the same pressure and friction from the calender. In papers of this kind, the amounts of filler added to the beaters vary from 5% to 40% for clay, and 5% to 20% for talc and agalite; the average is 10% to 15% for all kinds of fillers. In the case of papeteries, where a very high color and delicate tints are frequently desired, a filling or loading substance, as crown filler, having a higher color than the stock, is of very great use. Many special industrial papers must be loaded, some of them very heavily, in order to fulfill their special requirements; as an example, stereo-matrix board may be mentioned. In practice, this latter is built up by pasting several sheets together, the whole being then covered by a special and very tough tissue paper. On this, an impression is made from type already cast by the linotype or otherwise composed. After the impression is made, the **matrix,** as it is then called, is used as a mold for casting type to fit the rotary printing presses. In order to take a good impression without breaking, and to give a good cast, it is requisite that the board be properly loaded.

In general, the presence of filler tends to decrease the strength and size-fastness of a sheet; but this effect is not sufficiently marked to be of commercial importance, unless the amount of filler used be large. If the strength of paper is specified, proper selection and treatment of the fiber must be observed. Size-fastness has not the same significance in printing papers as in writings, because printing inks have an oily medium.

3. Names of Fillers.—There are comparatively few fillers in use in the paper industry in America. Those commonly met with are: *clay*, *talc*, *agalite*, *crown filler*, and *pearl filler*. For special purposes, small quantities of *barytes* (barium sulphate), *satin white*, or *chalk* are used. The following table gives the name, chemical formula, approximate composition, and principal uses for fillers commonly used in the paper industry:

PAPER FILLERS

Name	Formula	Analysis (approximate)	Use
NATURAL FILLERS: 1. China clay (kaolin).........	$H_4Al_2Si_2O_9$	46 % SiO_2 40 % Al_2O_3 14 % H_2O	(1) Book (2) Coating (3) Lower-grade writings
2. Talc......................	$_2Mg_3(SiO_3)_4$	63 % SiO_2 32 % MgO 5 % H_2O	(1) Lower-grade writings (2) Book
3. Agalite....................	$H_2Mg_3(SiO_3)_4$	63 % SiO_2 32 % MgO 5 % H_2O	Same as talc
4. Pearl filler (terra alba)......	$CaSO_4$	....	(1) Lower-grade writings
5. Barytes (heavy spar).......	$BaSO_4$	....	(1) Coatings (2) Litho papers (chiefly abroad) (3) Photographic
6. Chalk.....................	$CaCO_3$	....	(1) Cigarette
ARTIFICIAL FILLERS: 1. Crown filler (pearl hardening)....................	$CaSO_4{\cdot}2H_2O$	....	(1) Writings (2) Superfines
2. Calcium carbonate.........	$CaCO_3$	....	(1) Cigarette
3. Blanc fixe (artificial heavy spar, permanent white)....	$BaSO_4$	....	(1) Coating (2) Litho papers (chiefly abroad) (3) Photographic
4. Satin white................	$3CaSO_4 + Al_2(OH)_3$	29 % SO_3 13 % Al_2O_3 39 % CaO 19 % loss on ignition	(1) Coating

SOURCES AND CHARACTER OF FILLERS

CLAY

4. How Produced.—**Clay,** known also as **kaolin** and **china clay,** is formed by the weathering or gradual disintegration of a certain kind of rock called *feldspar;* it is one of the most widely distributed of our minerals. In England, clay is mined by first removing the dirt, or *overburden.* A pit is dug in the center of this cleared space, and a wooden pipe is sunk in the bottom of the pit to a depth of about 100 feet. The bottom of this pipe is connected to pumping machinery. The clay is washed down the sides of the pit, around the pipe, by means of streams of water. The resulting water and clay mixture enters the central pipe by holes left for the purpose. It is then pumped through long troughs, where the heavier impurities settle out. From the troughs, it flows to settling tanks, where the water is drawn off as the clay settles, until the remaining mass is pasty. This is dug out and is taken to the drying shed. After drying, the clay is ready for shipment.

In America, the first steps in mining clay are different, two methods being used: (*a*) the open-cut method, in which the overburden is first removed, and the clay is dug out and shoveled into small cars; (*b*) the shaft method, in which a shaft, usually vertical, is sunk, and the clay is mined and hoisted to the surface.

Regardless of the method employed in mining, the clay is then broken up in water; after which, it flows through a sand box and sand and mica troughs, to remove the heavy impurities. It is then screened through either stationary or shaking screens; after which, it is filter-pressed and dried. This wet method has been displaced by a dry method in some mines. In the latter case, the clay is taken direct from the mine to the drying shed. As soon as it is sufficiently dried, it is ground, and is then freed from heavy impurities by air separation. (See Fig. 3.)

Much of the southern sedimentary clay is not purified. It is mined, dried in open sheds by exposure to the air, and is shipped as crude domestic clay.

5. Impurities in Clay.—As would naturally be expected from its origin, the chief impurities in clay from a paper-making standpoint are *grit* and *iron.* The presence of an excess of iron results in a yellowish color, which, when not too deep, is sometimes

corrected by the use of a blue dye. English clays, for example, are sometimes tinted with ultramarine, to neutralize the yellowish color. The presence of grit is objectionable because of the wearing action on the paper-machine parts; it dulls the cutter knives, causes holes in the finished paper, and creates excessive wear on the printing plates. Some American clays are reddish-yellow when wet, but are white when dry; this is not an objectionable feature in paper making, since the color when dry should be the controlling factor.

It is widely believed that for other reasons besides color, English clays are superior to those found here in America; it is generally held that the desired qualities of finish, feel, opacity, and ink-absorbing power cannot be obtained by using domestic (American) clay alone. That there is a difference between domestic and English clays is shown by the variation in the time of slaking that characterizes the two groups. If lumps of domestic and English clay are put in a pan of water, it will be noticed that the time required for the water to disintegrate the clay lumps is much shorter for imported than for domestic clays. This difference is sometimes attributed to the fact that, while a wet process may have been used in purifying both classes, the English clay is allowed to settle and the water is then drawn off; whereas in America, filter presses are used, and the pressure employed in these presses is said to affect the speed of slaking.

6. Properties of Clay.—Chemically, clay is a hydrated aluminum silicate, containing approximately 40% Al_2O_3, 46% SiO_2, and 14 % H_2O (water). Physically, it is a yellowish to bluish-white substance, having a smooth, greasy feel, and possessing the characteristic property of making a "slip" or "slurry" on the addition of water. This **slurry** is merely a suspension of clay in water; but it may, at times, be almost a colloidal solution. If a sample of good English china clay be shaken or stirred with about four times its weight of water for two hours and then allowed to stand, it will be noticed that it settles very slowly. The time of stirring that is necessary will vary somewhat with the clay used. Talc or agalite when treated in the same way settles very quickly.

Clay is the most finely divided of our common fillers; it has a better color than most talcs or agalites, but not as good a color as pearl or crown filler. The discoloration may be due to iron or organic matter.

7. Quantity of Clay Used in Paper.—The quantity of clay used in book paper, which is the grade in which the greatest tonnage is used, is generally from 10% to 20% of the weight of the paper, although as much as 40% is sometimes found in papers that are to be given a very high finish, in order to take fine line-cuts or half-tone prints; smaller amounts, from 5% to 10%, are used in cheap writings, tablets, etc. Up to 5% is sometimes used in newsprint.

8. Methods of Handling.—Before clay is added to the beater, it is usually made up with water (1 to $2\frac{1}{2}$ pounds of clay per gallon) and screened to remove dirt. Sometimes $\frac{1}{4}$% to $\frac{1}{2}$% of sodium

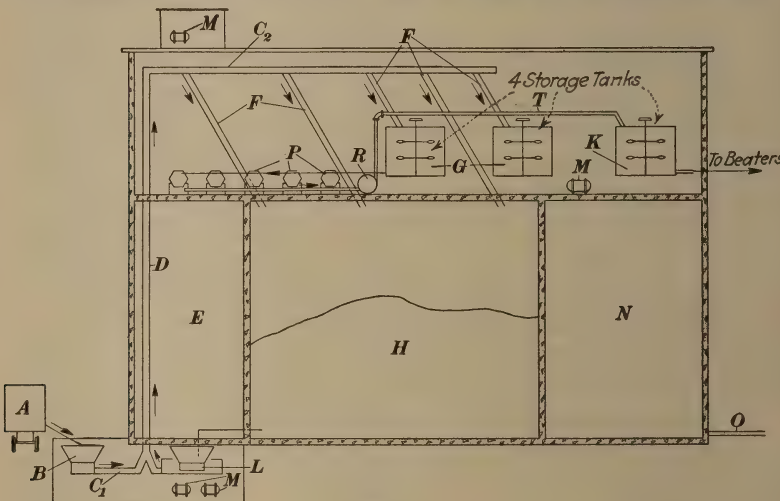

FIG. 1.

Legend: *A*, car; *B*, crusher; C_1 and C_2, spiral (worm) conveyors; *D*, bucket elevator; *E*, stairway; *F*, chutes to bins and tanks; *G*, mixing tanks; *H*, two storage bins, with spiral conveyor in the center of the bottom of each; *K*, 4 clay-milk storage tanks; *L*, automatic weighing hoppers; *M*, motors; *N*, alum and size house; *O*, platform; *P*, revolving screens; *R*, pump; *T*, pipe line to storage tanks.

silicate (based on the weight of clay used) is added when mixing with water; this is said to reduce greatly the viscosity of the solution, thus making the screening easier. Other alkalis, as caustic soda, bring about a similar result. Care must be exercised in the use of such substances, because of possible undesired effects on other materials, as size and coloring.

9. There are many ways of handling clay; sketches of two arrangements are given herewith. The first of these, outlined in Fig. 1, gives the course of the filler from railroad car to the storage tanks for the clay-and-water slip (slurry). The numbers refer

to the order or sequence of operations and the letters to the cut (illustration). 1, clay is transferred from cars A to a receiving hopper; 2, to crusher B; 3, to elevator feeder C_1; 4, to bucket elevator D; 5, to distributing conveyor C_2; 6, to bins H; 7, to reclaiming conveyor; 8, to scale hopper L; 9, to bucket elevator, as in D; 10, to distributing conveyor; 11, to mixing tanks G; 12, to revolving sifter screens P; 13, to storage tanks K.

10. A much simpler system is shown in Fig. 2. In this case, the clay (received in bulk) in cars A is shoveled into a chute B, which deposits it on a conveyor C. By this means, it is distrib-

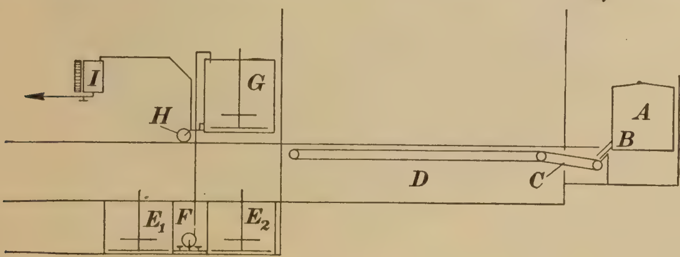

Fig. 2.

uted to any part of the clay storage bin D. As needed, clay is drawn from storage in carts, and is mixed with water in tanks E_1 and E_2. Each of these tanks should hold at least a 12-hours' supply. The agitators in these tanks should run at about 8 r.p.m.; they should pass close enough to the bottom to keep the clay thoroughly stirred up. Water is run in fast, and the agitator started; then the clay is added, gradually. From the mixers, the clay-milk is pumped to storage tanks G, and from thence to the measuring tanks I, there being one of the latter for every set of beaters. By placing tank G on a higher level, the clay slurry can be run by gravity to I, and from the latter to the beaters.

TALC

11. Occurrence.—The largest deposits of **talc** are in Vermont and northern New York. There are a number of varieties of talc, several sometimes occurring together; they differ from one another in color, hardness, and crystalline form, which accounts for the non-uniformity observed in the appearance of talcs when examined under the microscope. In some cases, each variety is mined separately, but more often as they occur, without separa-

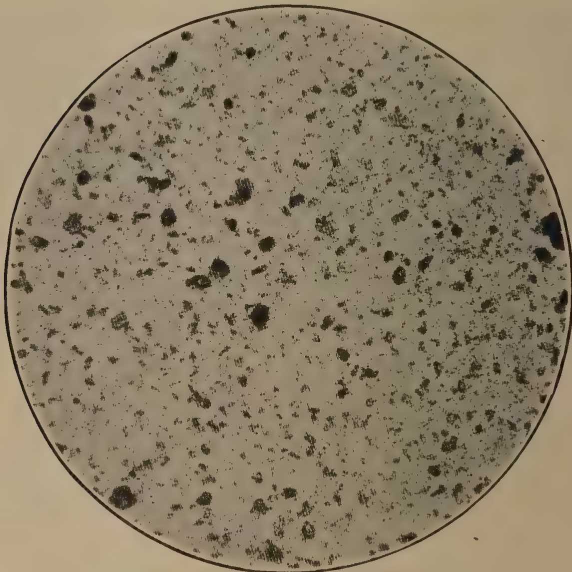

Fig. 3.

Fig. 4.

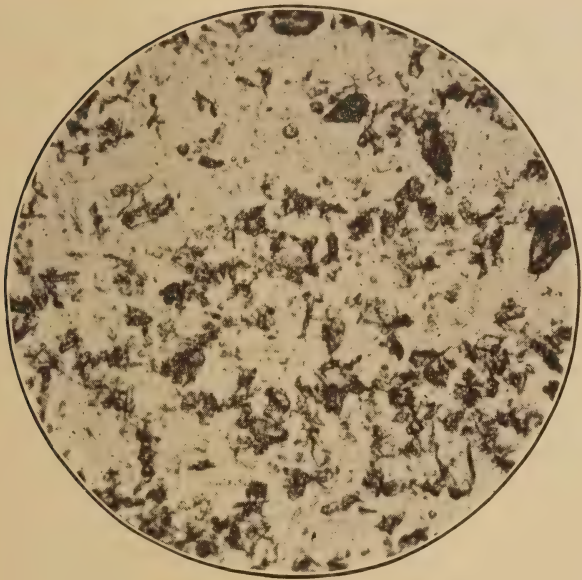

FIG. 5.

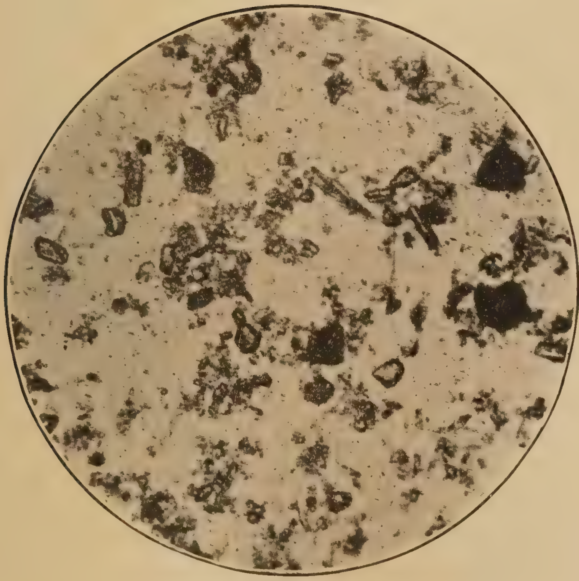

FIG. 6.

tion. In the early days of the industry, some surface mining was done; but the work is almost wholly underground now.

12. Treatment.—After the rock is brought to the surface, it is sorted, broken in a jaw crusher, then between rolls, and is then finally ground in a roller mill, a tube mill, or in an intermittent-operating pebble mill. The finished product is screened only, or is air-separated, depending on the degree of fineness required. Under the microscope, it is generally seen as flat plates of many sizes. (See Fig. 5.)

13. Properties.—Chemically, talc is a hydrated magnesium silicate, giving by analysis approximately 32% MgO, 63% SiO_2, and 5% H_2O (water). Physically, it is a greenish-gray substance having a soapy feel. Soapstone is a variety of talc.

14. Uses.—Talc is one of the natural fillers; it is much used in book papers, particularly those which are not to be used for fine printing, as line cuts, half-tones and other delicate plates. It is not suited to the latter, because the comparatively sharp, hard particles of talc are large enough to wear the printing plates badly, thus causing fine lines to blur. The use of talc tends to soften the sheet and improve the printing qualities, but to a less degree than does clay. To a certain extent, a shiny appearance and a slippery feel is given the paper. It is generally used in smaller quantities than clay, from 3% to 20%, averaging 10%.

The objections to its use are the possibility of the presence of grit, "shiners" (pieces of mica), carbonates, and iron. On the other hand, talc is cheaper than clay, has a higher retention (see Art. **23**), and it can be added to the beater dry, as received; whereas clay must be carefully mixed with water before adding. Probably its most desirable use is to soften the cheaper writing, tablet, papeterie, and similar papers, in which it is used in quantities of from 3% to 10%. It serves to remove that "woody" feel to some extent. Its color is, in general, poorer and less satisfactory than any of the other fillers.

OTHER FILLERS

15. Agalite.—In many ways, **agalite** is similar to talc; chemically, it is identical with talc. Physically, it is less soapy than talc, but has much the same general color. Under the microscope, it is supposed to appear as long needle-like crystals. A careful examination of many commercial samples of talc and

agalite has shown that these substances grade into each other as regards crystal form.

The properties of agalite, drawbacks to its use, etc., are much the same as in the case of talc, but the former is considered to be more wearing on paper-machine clothing parts and on printing plates; it tends to wear the fine lines on the latter and to fill them with dust. For this reason, it is not used to the same extent as clay or talc, especially in book papers. Agalite should not be used in quantity in papers that are to be cut or punched, because it dulls the steel cutting edges. Its color is, in general, a gray, somewhat lighter than talc, and lacks the characteristic green tint of the latter.

16. Asbestine.—**Asbestine** is a filler that much resembles talc and agalite; under the microscope, it appears as a mixture of these two. Its use and properties are a sort of a compromise, as would be expected from this crystal formation. (See Fig. 6.)

17. Crown Filler.—Crown filler has by far the purest white color of any of the fillers; it is also known as **pearl hardening.** Crown filler is an artificial (manufactured) product, as distinguished from clay, talc, agalite, and pearl filler, which are mined. It is made as a precipitate by the interaction of solutions of $CaCl_2$ and $NaHSO_4$. Chemically, it is calcium sulphate, with two molecules of water of crystallization $CaSO_4 \cdot 2H_2O$. The dry substance shows, on analysis, 79% $CaSO_4$ and 21% H_2O. By *water of crystallization* is meant water chemically combined, so that a substance containing it can appear to be quite dry while containing, in some cases, as much as 50% water. Crown filler appears on the market as a wet powder that contains 33% water, of which 21% is chemically combined and the remainder is mechanically mixed. (See Fig. 4.)

Owing to the methods of manufacture, crown filler can be kept free from grit and very low in iron and in acid content. Extensive mill and laboratory tests have shown that free acid, figured as hydrochloric acid, should not be over 0.05%, based on the sample as received; more than this may cause trouble with the rosin sizing. It is the most soluble of the fillers, about 30 pounds being dissolved in 1000 gallons of pure water at ordinary room temperature. At this rate, from 60 to 80 pounds are dissolved in the water contained in an ordinary 1000-pound beater; therefore, if less than 10 pounds of crown filler per 100 pounds of fiber

is added to the beater, almost no calcium sulphate is found in the furnished paper. The solubility is less when hard water is used, and it is decreased by the addition of alum. The quantities of crown filler used are generally 40% to 50% of the fiber furnish.

This filler is particularly useful in high-grade papeteries, where a high white color or delicate tints are desired. As it is the most expensive of the fillers and has the lowest retention, its use is necessarily confined to the better grades of paper. When present, it interferes somewhat with the rosin sizing of the sheet, because, owing to its solubility, enough calcium sulphate is in the solution to react with the rosin size, precipitating a calcium resinate, or calcium soap, which has no sizing value. A similar effect on sizing is observed when very hard water is used.

18. Pearl Filler.—Chemically, **pearl filler** is the same as crown filler, except that there is no water of crystallization and only about 1% of mechanical water. It is found in nature, as are talc and agalite, and has merely to be ground and sifted to prepare it for use. The alkalinity is about the same as talc, 1% to 2%, figured as $CaCO_3$, and the grit is less. In color, it is not equal to crown filler, but it is far better than in any of the other fillers. It is less expensive than crown filler and its retention is greater. The chief reason for its greater retention is that of each 100 pounds of crown filler added to the beater, 33 pounds is water, while pearl filler is almost free from water. Pearl filler is used chiefly in medium-grade papeteries and writings, and it is added to the beater dry.

FILLERS FOR SPECIAL PAPERS

19. Chalk.—In addition to those already described, a number of other fillers are used for very special papers. **Chalk** (the ground mineral), or calcium carbonate (precipitated for this purpose), is used in amounts as high as 30% in cigarette paper. Its use speeds up the burning of the paper, because, when the paper is heated, carbon dioxide gas is given off; this opens the pores of the paper and promotes combustion. Chalk also improves the color of the ash.

20. Barytes.—**Barytes,** or **barium sulphate,** is used in photographic papers on account of the special surface imparted to the sheet; it is quite expensive, and its retention is low because of its weight. It is also used in some special printing papers that must be very flat, it being held that the weight of the filler holds

the paper down. This filler is usually prepared by adding a soluble sulphate to a solution of barium chloride.

21. Oxide of Iron and Wilkinite.—**Oxide of iron** is sometimes used to color leather board and box board, and to act as a filler at the same time. This material is said to give trouble, however, due to the pitting of press and calender rolls; this effect is especially to be noted on the latter, if a water finish is being applied.

Recently, work has been done on a very highly colloidal, clayey substance that is known to the trade as **wilkinite,** geologically called bentonite. This material appears to have the property of retarding the settling of clay suspensions. The indications are that it will also increase the retention of filler in paper.

22. The Microscopic Appearance of Fillers.—In Figs. 3, 4, 5, and 6 are shown photomicrographs of four commonly used fillers. These were prepared by the Paper Section, Bureau of Standards (United States). They show the marked difference between the finely divided, colloidal clay and the highly crystalline crown filler; also, the similarity between talc and asbestine. A few of the needle-shaped crystals are visible, especially in the asbestine. The magnification in each case was 100 diameters.

RETENTION OF FILLERS

23. Per Cent of Retention.—By retention of filler is meant the pounds of filler found in the paper for each 100 pounds of filler added to the beater. To find the per cent retention, divide the weight of the filler in the paper by the weight of filler added to beater and multiply by 100; thus,

$$\text{per cent retention} = \frac{\text{weight of filler in paper}}{\text{weight of filler in beater}} \times 100$$

Instead of using the weights of filler, the percentage of filler by weight may be used, in which case, care must be taken in calculating retention that the per cent filler in the beater and that in the finished paper are figured on the same basis, which should be the weight of bone-dry fiber. Proper corrections should be made for the moisture content of the original filler and of the filler as it occurs in the paper, for the ash content of the fiber furnish, etc. Some fillers contain water of constitution (part of the molecule), besides moisture held mechanically; all this water is lost in determining the ash content. The particular formula to be used in any given case should be picked out after considering the

accuracy of the final result that is desired. The per cent retention of the filler, as determined by the amount and character of the ash, is used in calculating the amount of filler that must be added to the stock. Allowance must be made for the solubility of the filler in some cases, particularly when calcium sulphate is used. (See Art. **33.**)

When waste paper from the mill is used, especially "broke" (spoiled paper), consideration must be given to any filler that may be contained in it. It will be seen, too, that any filler contained in white water that may be used in the beater or on the machine, will affect the retention of the filler added; this water may become saturated, so to speak, with filler.

24. Conditions Affecting Retention.—The retention of any given filler will vary widely, according to stock and machine conditions. Other things being equal, retention increases as the weight of the sheet, the slowness (hydration) of the stock, or as the length of the fiber increases. It decreases as the speed of the machine increases, and as the amount of suction on boxes and rolls increases. Retention is greater in a well-sized sheet than in a slack-sized sheet; with mechanical and sulphite pulps, it seems to decrease with the length of fiber. Other conditions being the same, but using different fillers, the retention increases as the size of the filler particles increases, and as the specific gravity or weight per cubic foot decreases. Retention decreases as the solubility and moisture content of the filler increases. Other conditions affecting retention are the amount of shake of the machine, and the quantity of fresh water or of white water used. The retention is less than the normal by from 10% to 20%, if the amount of filler added is less than about 5% or greater than 30% of the weight of the fiber; this last does not apply to crown filler, which reaches its maximum retention with additions of 50% to 60%, nor to pearl filler.

Unfortunately, little retention data for pearl filler are available. It seems, however, that the ratio of bone-dry calcium sulphate, with no water of crystallization retained, to bone-dry calcium sulphate added, is approximately the same for both crown and pearl fillers, when large amounts are used. Crown filler usually contains about 33% of water whereas pearl filler contains almost none at all. If the retention is based on the actual pounds of filler added, irrespective of moisture content, the retention of pearl filler would be about half again as great as that of crown filler.

25. Some Retention Data.—The following data are based on papers having a folio weight (standard substance number or weight per ream of 500 sheets, 17 inches × 22 inches) of about 20 pounds, an addition of filler of 10% to 20%, and a machine speed of 100 to 200 ft. per min. The figures are average results; the papers were writings and envelopes, with a few book papers. The retention to be expected in book paper of medium weight is about

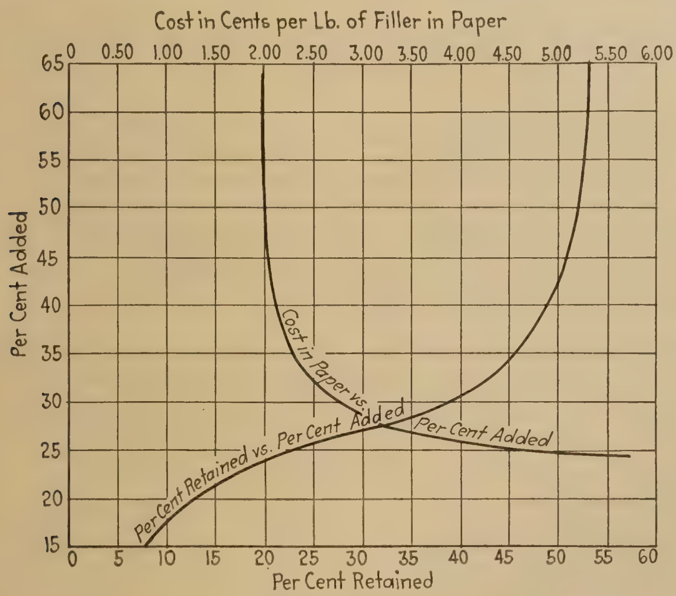

Fig. 7.

10% lower than the figures obtained, which were: talc, 82%; agalite, 75%; clay, 70%.

For crown filler, the following figures for the same sheet weight and range of machine speed are given. The papers were writings and papeteries.[1]

Per Cent Added (Pounds Per 100 Pounds of Pulp)	Per Cent Retained (Based on Filler Added)
10	0.0
20	13.5
30	39.5
40	49.0
50	52.0
60	53.0

[1] Papers for fancy correspondence boxes, and the like.

26. In Fig. 7, a curve is given of the retention of crown filler, showing how this varies with the amount added. Another curve is also given, which shows the variation in the cost per pound of filler in the paper with the amount added to the beater; the rapid increase in cost when small amounts are added is very evident, and is due to the large percentage lost. The cost of this filler delivered to the mill was $1.08 per 100 pounds when this cost curve was drawn.

27. Other conditions than those mentioned being constant, retention of filler will vary as follows:

Retention Increases	Retention Decreases
As weight of sheet increases;	As solubility of filler increases;
As machine speed decreases;	As amount added to beater decreases below 5%;
As engine sizing changes from slack to good;	As amount added to beater increases above 30% (except crown filler).
As slowness of stock increases;	
As length of fiber increases;	
As size of filler particles increases;	
As specific gravity of filler decreases.	

28. When to Add the Filler.—The proper time for adding filler is generally thought to be as soon after "furnishing" as possible, and before the addition of size and alum, as the precipitation of size tends to fix the filler in the fiber. The usual practice is to add: first, filler; then, rosin; and, last, alum.

Retention will be increased by the use of starch or sodium silicate; but it is doubtful whether the increase warrants the use of these materials for this cause alone. Some even advocate boiling filler and starch together. It has also been recommended to mix the clay with separately boiled starch, and then add rosin size to the mixture; after which the whole is added to the beater. Unfortunately, there is little actual data available. Clay, however, should be added, and it should be thoroughly mixed with the stock, before alum is added; otherwise, the acid of the alum will destroy the colloidal properties of the clay, thereby lowering retention, giving poorer finish, etc.

QUESTIONS

(1) What substances may paper contain, other than fiber?

(2) How is clay produced? How does it differ from talc?

(3) What chemical difference is noted between crown filler and pearl filler?

(4) How is clay usually added to the beater? (*b*) talc?

(5) Would you expect any difference in the retention of crown filler in soft water and hard water? Explain your answer.

ANALYSIS OF FILLERS

29. Sampling.—The sampling is done by opening 5% to 10%, preferably 10%, of the barrels or packages, as received from the car, and taking a small portion of each, making the weight of the total sample about 5 pounds. In case of a shipment in bulk, it is best to take the sample at frequent and regular intervals, as the shipment is being unloaded. From a car of clay, the filler most commonly shipped in bulk, the sample thus taken should weigh about 50 pounds, and should represent both the fine and coarse portions. The lumps should be broken up and the sample quartered down, until it will about fill a Mason jar; this is kept in an air-tight container until the analysis is to be performed.

30. Preparation for Analysis.—The 5-pound sample is carefully mixed, all large lumps are broken up, and the whole is quartered down to about 50 grams. The analyst will do well at this point to determine whether the filler is clay, talc, agalite, calcium sulphate, etc. A qualitative test may also be made for acidity.

31. Moisture Content.—Mechanically combined moisture is determined on 2 grams of this sample by drying at 105°C. to a constant weight. The chemically combined moisture may be determined by placing this dried sample in a crucible and heating at the full heat of a Meker burner until a constant weight is secured; or by heating 2 grams of the original sample in the same manner, and then subtracting the mechanical (surface) moisture from the result. In the case of crown filler, the total moisture is determined by igniting a 2-gram sample over a Meker burner to constant weight; from this result, the chemically combined moisture may be calculated, the molecular formula for crown filler being $CaSO_4 \cdot 2H_2O$. Subtracting this result from the original 2 grams taken for analysis, the mechanical moisture is obtained.

32. Color.—Color is determined by comparison with a standard sample that has been selected for color. Small amounts of the sample to be compared and of the standard are pressed together on a black paper, with a polished steel spatula. Any difference in color can then be readily seen, and the sample is reported to be as good as standard, yellower, grayer, or whatever difference is observed.

33. Fineness.—Fineness may be determined microscopically, by elutriation, or by the sieve method; but none of these three

methods is applicable to calcium sulphate or other fillers that are appreciably soluble. Fineness is determined most simply microscopically. A very small amount of filler is placed on a glass slide, with a small amount of water, and a cover glass is placed over the mixture. It is examined under low power of the microscope, comparing the sample with the standard, which has been treated in the same way. If a microscope is not available, 200 grams of clay are mixed thoroughly with 1000 c.c. of water and strained through a 200-mesh, silk, bolting cloth, by use of a gentle stream of water. The material remaining on the screen is dried and weighed. This will give a fair estimate of the per cent of grit present.

34. Elutriation Tests.—The elutriation test on a filler gives the per cent of grit or coarseness, but the method is very com-

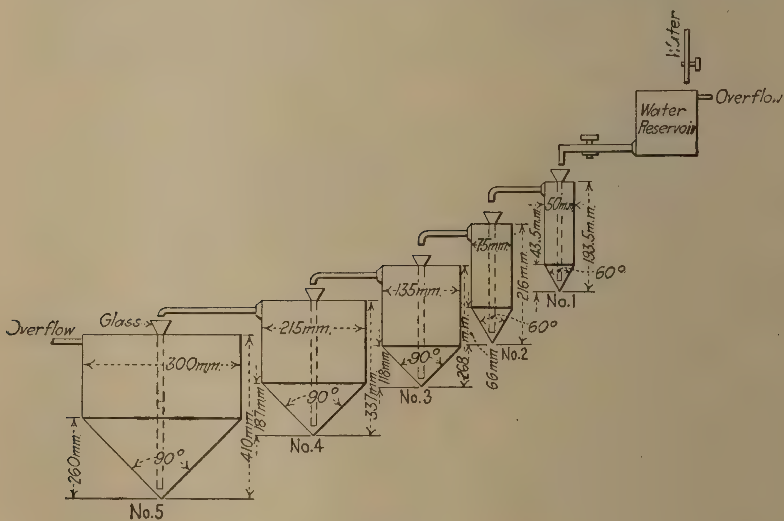

FIG. 8.

plicated; for general purposes, microscopic analysis is sufficient. The more grit present the poorer is the material as a filler. Binns' apparatus is very satisfactory for a careful elutriation test, and should be used when very careful analysis is necessary. The arrangement of this apparatus is shown in Fig. 8. In making the test, 50 grams or 100 grams of bone-dry clay are weighed out, thoroughly slaked (preferably in some sort of tumbling device in which duplicate results can be obtained), and strained through a 100-mesh sieve into No. 1 receptacle. Water is then run in

at the rate of 2.8 c.c. per second, giving a rate of flow of 1.5, 0.7, 0.18, 0.08, and 0.04 mm. per sec. in the various receptacles, which progressively increase in size, the smallest having, of course, the highest rate of flow. The flow should be continued until the water from the last receptacle is clear; then weigh the various residues. There will probably be little or none in the first two, and it will probably be found that the residue in the third receptacle is the best measure of the fineness of the sample. There are several other types of elutriating apparatus on the market, as those of Schöne or Hilgard. This subject is very fully covered in Wiley's "Principles and Practice of Agricultural Analysis." The Schöne apparatus gives very accurate results.

35. The following method will give tests for comparing two fillers. A 10-gram sample of the filler is placed in a glass cylinder, $11\frac{3}{4}$ inches high and $1\frac{5}{8}$ inches in diameter, and which holds 400 c.c. The filler is thoroughly shaken up with a small amount of water, and the cylinder is filled to the top. From a large bottle, 58 inches above the bottom of this glass cylinder, 2500 c.c. is allowed to pass through the cylinder from a glass tube, $\frac{1}{8}$ inch in diameter, extending to the bottom of the cylinder. The residue is then filtered on a tared filter, dried, and weighed; this gives the amount of grit or coarseness in the filler. Variation in the rate of flow of the water can be made to suit special conditions. Other things being equal, the greater the rate of flow the larger the particles carried out of the cylinder, and the smaller the apparent amount of grit in the sample. The amount of grit in any filler should be less than 1.5%. When a partially soluble filler is tested, the water used must be saturated with it, and the temperature must be kept constant.

36. Sieve Test.—For the sieve test, which is not so reliable as the elutriation test, a set of standard sieves, from No. 100 to No. 325, inclusive, is recommended. These numbers have been given to a scientifically determined series and correspond approximately to the ordinary mesh. These should be small, and be light enough to permit the residue to be weighed on the sieve without transferring to tared filter paper. This method is as follows:

Place the weighed sample of clay in a beaker and add distilled water. For a 50-gram sample, add 500 c.c. of water. Let stand for one-half hour, and then agitate thoroughly, but without grinding. Let stand for a few minutes, for the coarse material

to settle in the bottom, and decant through the weighed sieve, which has been previously cleaned and dried in an oven at 105° to 110°C. Decant a small portion slowly through the screen, and wash out with water. Gradually transfer the suspended material, finally leaving the coarse particles on the sieve. With proper manipulation, a large portion of the sample will pass through the sieve during the process of transference. If the contents are dumped on the sieve at one time, the coarse particles will clog the holes, which will cause the sieving operation to prove difficult, often impossible, unless the sediment is stirred with the hand. Such hand stirring or rubbing of the material through the sieve is strongly to be condemned; it not only forces through the larger particles but it also permanently distorts the apparatus, so that the sieve is rendered worthless. Gently tap the sieve while washing under a stream of water. Toward the end, it will be found more efficient to place some water in a dish and to set the sieve in this; then, by a shaking motion, the sieve is washed from below. Such washing will remove the fine particles much more quickly than by placing water on the sieve with the residue. By having a dish painted black, the thoroughness of washing a white pigment will be apparent. Finally, heat the sieve for 1 hour at 105° to 110°C., cool, and weigh.

When properly used and cared for, sieves should be reliable for a number of years. No washers, shot, or other device for hastening the sieving process should ever be used. The following table gives the sizes of the wires and openings for standard sieves from No. 100 to No. 325.

Sieve No.	Opening in Inches	Wire Diameter, Inches
100	0.0059	0.0040
120	0.0049	0.0034
140	0.0041	0.0029
170	0.0035	0.0025
200	0.0029	0.0021
230	0.0025	0.0018
270	0.0021	0.0016
325	0.0017	0.0014

37. Alkalinity.—Alkaline fillers are likely to have an injurious effect on sizing and coloring, and where they must be used, proper precautions, such as in selecting colors, should be taken.

The alkalinity due to carbonates and bicarbonates may be determined by any of the standard methods for the determination

of carbon dioxide CO_2; that is, by treating with acid and weighing the CO_2 absorbed in KOH or soda lime. The advantage of the following method is that it does not involve the purchasing of elaborate apparatus, and it is more accurate and quick for routine work to determine small amounts volumetrically and gravimetrically.[1]

The apparatus consists of two 1000-c.c. gas-washing bottles, filled with 20% solution of NaOH for the purpose of removing CO_2 from the air. These flasks are connected to a 250-c.c. Erlenmeyer flask that is fitted with a rubber stopper, through which a dropping funnel is passed. The outlet of the Erlenmeyer flask is connected with a train, which consists of four 50-c.c. Nessler tubes, fitted up as washing bottles. The tube nearest the Erlenmeyer flask remains empty, and serves as a trap for any vapors or solid particles that may be carried over mechanically from the generating flask. The next three tubes contain exactly 25 c.c. of N/2 NaOH solution. The last tube is connected to the suction, and a constant current of air, free from CO_2, is drawn through the apparatus. In making the determination, 10 grams of filler is weighed into a mortar and triturated with two 15-c.c. portions of water. The residue is then washed into the Erlenmeyer flask, the total volume of solution being about 50 c.c. The apparatus is connected up. The pinch cocks are opened on the connection between the Erlenmeyer flask and the wash bottles on the one side, and the first and second Nessler tubes on the other side. A current of air, free from CO_2, is drawn through the apparatus at a moderate rate. During this time, the Erlenmeyer flask is shaken occasionally. In a dropping funnel 50 c.c. of a 10% alum solution is placed, the stop cock is opened, and the alum is allowed to run into the Erlenmeyer flask, care being taken that the alum does not run into the flask fast enough to force the filler emulsion backward into the wash bottles. A column of alum solution should be allowed to remain in the stem of the funnel as a seal. An hour after the alum solution is all added, the pinch cocks are closed and the suction shut off. The contents of the last three Nessler tubes are washed carefully into a flask, and are titrated with standard N/2 acid, using phenolphthalein as an indicator, until an end point is reached; then methyl orange is added,

[1] Quantitative Analysis; Treadwell and Hall's Quantitative Analysis and Mahin's Quantitative Analysis are suggested as reference works on laboratory procedure and general analysis.

and the titration is completed. A blank consisting of 25 c.c. of N/2 $NaOH$ solution is titrated with N/2 acid in the same manner. Phenolphthalein titrates one-half the carbonates present and all of the hydrates present, and methyl orange titrates the other half of the carbonates. Calculate the alkalinity in terms of calcium carbonate, by multiplying the methyl orange titration by 2 and then by 0.02504.

The alkalinity due to calcium carbonate is of chief importance in a paper filler, and should be kept under 5%. Excess alkalinity tends to kill rosin size, causes excess foam, and may alter the shade of certain dye stuffs.

38. Iron.—Take 2 grams of sample and dissolve in 10 c.c. C.P. Conc. HCl. If there is any residue, fuse it with sodium carbonate, dissolve in concentrated hydrochloric acid, and add to the main portion of the solution. Wash dissolved filler into a 100-c.c. Nessler tube, and add a few drops of a N/10 $KMnO_4$ solution, to be sure that the iron is oxidized to a ferric condition. The color of the potassium permanganate $KMnO_4$ should persist for at least two minutes. Add 10c.c. of potassium sulphocyanide $KCNS$ solution (2% solution), and make up to 100 c.c., mixing thoroughly. Compare immediately the resulting color with a standard that has been prepared at the same time, by adding a standard iron solution (1 c.c. = 0.00001 gram Fe_2O_3) to another Nessler tube, which contains two or three drops of $KMnO_4$ solution, 10 c.c. of $KCNS$ solution, and 85 c.c. of H_2O, until the same color is produced in both tubes. The number of cubic centimeters of iron solution used multiplied by 5 gives the parts of Fe_2O_3 per million. Iron solution is best prepared by dissolving 1 gram of pure iron wire in a small amount of H_2SO_4, oxidizing this with N/10 $KMnO_4$, and making up to 1000 c.c. By diluting a little of this solution 100 times, a solution containing 0.00001 gram Fe_2O_3 is obtained. The amount of iron in fillers used in paper making should be kept very low, especially in a filler partially soluble in water, as crown filler, where the iron content should not exceed 0.005%. In fillers that are insoluble in water, the presence of iron is usually detected by the high yellow color that makes them unsatisfactory for paper making.

QUESTIONS

(1) How should a sample of filler be taken and prepared for analysis?

(2) Explain the testing of a filler for alkalinity. Why is this important?

SECTION 4

LOADING AND ENGINE SIZING

(PART 2)

By Judson A. DeCew, B. A. Sc.

Revised by W. G. MacNaughton and T. Linsey Crossley

ENGINE SIZING

HISTORICAL

39. Definition.—**Sizing** is a treatment given to paper to make it water resistant. When paper is made without sizing, it is like blotting paper and very unsatisfactory to write on with fluids.

Paper is sized in two ways: (*a*) tub sizing (or top sizing), the sizing material being applied *after* the paper is made (this process is described in *Hand-Made Papers and Tub Sizing*, Vol. V); (*b*) engine sizing, the sizing material being applied while the paper is being made, usually in the beater (beating engine).

40. Rosin Sizing.—A compound of rosin (colophony) is the material usually employed in engine sizing. Chemically, rosin consists largely of abietic acid, which yields *rosin soap* when heated with an alkali, just as fats make common soap when treated with soda or potash. Until 1807, all paper was tub sized by dipping the finished paper into a thin glue. In that year, Moritz Illig, of Frankfort, Germany, devised a process for sizing with rosin soap while the paper stock was being prepared.

41. Effect of Adding Alum.—Rosin soap dissolves in water; but when this solution is treated with aluminum sulphate, commonly called *papermaker's alum*, a change takes place—the rosin

part of the soap and the aluminum part of the alum are separated. What happens to the rest of the two compounds is not of immediate interest. The mixture becomes curdled, and the curd contains both rosin and aluminum hydrate. Now, if the rosin soap be dissolved in water, added to the paper stock, and then treated with alum, this curdling occurs among the fibers. The curds of rosin and alumina are tiny and very sticky, and they become attached all over the fibers. Illig considered that the sizing effect was produced by the rosin; others, for nearly fifty years, thought that the aluminum hydrate was the sizing agent. In 1878, Wurster showed that Illig was right. When the fibers, in the form of a sheet, are dried on the paper machine, the curd, of course, dried with them. The heat of the dryers and the pressure of the calenders undoubtedly help the curdy matter to give ink-resistant properties to the paper; but, even when fiber sheets, impregnated with this fine sticky curd, are dried in the air without heating, they have some ink-resistant properties.

MATERIALS USED IN SIZING

ROSIN

42. Sources of Rosin.—Rosin is produced from the gum (oleo-rosin) of the southern pine, chiefly from the long-leaf species. When made from the gum that exudes from the living tree, it is referred to as **gum rosin.** When made from pine-stump wood or other fat resinous wood by the steam and solvent process, it is referred to as **wood rosin.**

43. Gum Rosin.—In the production of gum rosin, the surface of the living tree is chipped weekly during warm weather, and there exudes from the freshly cut sapwood many drops of a clear, pitch-like, viscous liquid. As it flows from the tree, this liquid is collected in a cup, and is generally covered with a layer of water, which collects from rains, the water protecting the liquid from evaporation. This liquid is the gum, or oleo-rosin. The gum is gathered and put into copper stills, where it is distilled in the presence of water. Turpentine, the volatile part of the gum, is distilled away with steam, the rosin being left in the still. The rosin is then drawn off, strained through a wire screen and cotton batting, and barreled.

44. Wood Rosin.—In producing wood rosin by the steam and solvent process, the wood is first reduced to suitable small chips; it is then steamed in extractors, to distill off the turpentine and most of the pine oil. The chips are next treated with a solvent, to extract the rosin and the remainder of the pine oil. The resulting crude solution is passed through evaporators, to recover the solvent and pine oil from the crude rosin, which is subjected to a special finishing treatment, to eliminate the residual heavy end of the pine oil.

45. Grading Rosin.—Gum rosin, in which the yellow color predominates, is graded by color into thirteen grades—from the darkest color, which is B, the lowest grade, to the palest color, which is X, the highest grade. The grades are divided into four classes: namely, B, D, and E, which are classed as *low-commons;* F, G, and H, classed as *high-commons;* I, K, and M, *classed as mediums;* and N, W-G, W-W, and X, classed as *pales.* Wood rosin as now commercially produced, in which the ruby-red color predominates, is generally described as F wood rosin; it is suitable for sizing papers where high white is not required.

The grades of gum rosin most used for paper size are F and G. The reason for this is that, although grades darker colored than F give good sizing results, they are not much used, because of dirt and foreign matter. In general, grades lighter than G are not hard enough to give the best results in sizing.

46. The Rosin Package.—Rosin is sold in units of 280 pounds, gross weight. The wooden barrel of rosin, often called the *round barrel,* weighs approximately 500 pounds, gross, and the customary carload of rosin contains 100 round barrels. The tare of rosin in wooden barrels varies from 16% to over 20%; it averages about 18%. The average wooden round barrel, therefore, contains approximately 410 pounds of rosin, net weight.

The steel barrel, now used to some extent, averages 485 pounds, gross weight. Since the steel barrel itself weighs 15 pounds, the net weight of the rosin is 470 pounds; hence, there are two *units* of 235 pounds net weight in every steel barrel.

47. Chemical Characteristics of Rosin.—Rosin consists of 90% to 92% of anhydrous abietic acid $(C_{20}H_{29}O)_2O$ (molecular weight, 586.47). The molecular formula for abietic anhydride was formerly written $C_{44}H_{62}O_4$. Abietic acid forms water-

soluble resinates with alkalis. The remaining 10% to 8% (the resenes of the rosin) being inactive to alkali, remain in colloidal suspension in the aqueous solution of the water-soluble resinate. The whole mixture is *rosin size.* If less acid be used than is required to react with all the abietic acid present in the rosin, the remaining unacted-upon abietic acid will remain in suspension in the size, in the same manner as the resenes. Consequently, by varying the ratio of alkali to the rosin, sizes containing different percentages of free rosin (abietic acid and resenes) may be obtained.

ANALYSIS OF ROSIN

48. Commercial Grading.—To test rosin for color, it is necessary to have color standards. These are obtained as a set of *standard rosin cubes*, graded for color, which at present (1928) may be purchased from D. C. Campbell, Jacksonville, Fla. The U. S. Bureau of Standards prepares sets of standard glass cubes, graded for color, which should be used if procurable. Until the glass cubes have a wider distribution, the use of the rosin cubes will be satisfactory, provided they are not too old.

The glass cubes must not be compared with the rosin against a clear sky, as the result will be erroneous; always make the comparison against a white paper or translucent film. Also, do not hold the glass cube and rosin in the hand when comparing against the white paper background; they must always be viewed through the long black box that is provided for the purpose, or the result will be incorrect.

49. Reagents.—Prepare standard solution of *alcoholic potash*, as follows: Dissolve 29 grams of pure KOH (preferably purified by alcohol) in 1 liter of 95% ethyl alcohol. The alcohol and KOH should be allowed to stand until all the KOH is dissolved; it should then be filtered rapidly or siphoned off, to remove any insoluble carbonate.

NOTE.—The alcohol should be tested with a little NaOH before using, and if it gives a decided yellow solution, which shows that it contains an excessive amount of aldehyde, treat as follows: Dissolve about 1.5 grams of $AgNO_3$ in 3 c.c. of water, and add to 1 liter of the alcohol; shake thoroughly. Dissolve 3 grams of NaOH in 15 c.c. of warm alcohol, cool, and add to the main solution; shake thoroughly, allow to settle, then siphon off the clear liquid, and distill. Add a few pieces of pumice, to prevent bumping.

50. Procedure.—Dirt and foreign matter: Unless the rosin is quite dirty, no quantitative estimation is necessary. In case a quantitative estimation is desired, dissolve 25 grams of rosin in warm alcohol; filter through a tared filter paper, wash with alcohol, dry, and weigh the residue.

SAPONIFICATION NUMBER: Weigh 2 grams of powdered rosin into an Erlenmeyer flask of 300-c.c. capacity. Add 25 c.c. of N/2 alcoholic potash, and boil for 2 hours, using a reflux condenser. Shake the flask frequently, with a swirling motion, to prevent the rosin from sticking to the sides of the flask above the liquor line. Cool, titrate the excess of KOH with N/2 acid and phenolphthalein, and calculate the milligrams of KOH consumed per gram of rosin; this will be the **saponification number.** In each case, run a blank on the KOH solution by boiling 25 c.c. of the solution in exactly the same manner as the saponification proper is carried out.

$$1 \text{ c.c. N/2 KOH} = 28.06 \text{ mg. KOH}$$

ACID NUMBER: Dissolve 2 grams of powdered rosin in warm alcohol (neutral to phenolphthalein); cool, and titrate the solution with N/2 KOH, using phenolphthalein. Express the result as milligrams of KOH consumed per gram of rosin; this is the **acid number.** To estimate actual amount of abietic acid, the following may be used:

$$1 \text{ c.c. N/2 KOH} = 0.1512 \text{ grams (151.2 mg.) abietic acid, } C_{20}H_{30}O_2$$

ESTER NUMBER: The **ester number** is the difference between the saponification number and the acid number.

UNSAPONIFIABLE MATTER IN ALCOHOLIC SOLUTION: Saponify 5 grams of rosin by boiling for 2 hours, with an excess of N/2 alcoholic potash. Evaporate off most of the alcohol, add about 100 c.c. of the water, and extract in a separatory funnel with acid-free ether, exactly as in the determination of free rosin (Art. 88).

MATTER UNSAPONIFIABLE IN AQUEOUS SOLUTION: Boil 5 grams of rosin for 4 hr. in an aqueous solution containing 1 gram of sodium carbonate, and then extract as above. This result represents more nearly the rosin unacted upon in determining the acid number, and it is considered to be the unsaponifiable matter, insofar as size making is concerned.

ASH: The determination of ash is seldom necessary. If required, it may be accomplished by igniting 5 grams of rosin under a hood in a platinum crucible to a white or light-gray residue. Cool in a dessicator and weigh.

SODA ASH AND ALUM

51. Soda Ash.—The reaction whereby a soap is made is called **saponification,** and the alkali generally used in the reaction is soda ash, chemically termed sodium carbonate Na_2CO_3. There are two forms of soda ash—light, or bulky, and heavy, or dense, the light variety being more convenient for size making.

The active saponifying part of soda ash is sodium oxide Na_2O, and pure sodium carbonate contains 58.5% of Na_2O. Commercial soda ash is nearly pure, and it is usually sold as 58% Na_2O. One hundred pounds of rosin requires about 16 pounds of 58% soda ash for saponification. If the amount of Na_2O falls below 58%, the quantity of soda ash would have to be increased in proportion.

In some cases, sodium hydrate (caustic soda) $NaOH$ is used; this saponifies the rosin more rapidly, but is more difficult to handle. In more recent years, the use of sodium silicate $Na_2Si_4O_9$ has been investigated and recommended by Blasweiler, and the results of his experiments are very promising. For detailed information on this subject, the student is referred to the original literature.

52. Papermaker's Alum.—**Alum** is the trade name for aluminum sulphate $Al_2(SO_4)_3 \cdot 18H_2O$ (**papermaker's alum**). The term should be properly restricted, however, to one of the double salts of aluminum sulphate and an alkali sulphate, as potassium-aluminum sulphate $K_2SO_4 \cdot Al_2(SO_4)_3 \cdot 24H_2O$, and the first alum used in paper making was this double salt, since it could be obtained in a very pure state. It is still used by some paper makers, in spite of its greater cost; but this is probably unnecessary, as a very pure aluminum sulphate, containing 16.85% of alumina Al_2O_3, can readily be obtained. The common grades of aluminum sulphate contain about 0.5% of iron oxide Fe_2O_3 and some alumina Al_2O_3 and silica SiO_2, but not sufficient in amount to injure ordinary grades of paper.

53. Manufacture.—Commercial alum is made by dissolving the mineral bauxite, hydrated aluminum oxide $Al_2O_3 \cdot 2H_2O$, in

sulphuric acid; and despite variations and impurities in the mineral, commercial aluminum sulphate is very uniform. The filtered solution is evaporated until the amount present in the compound would cause the alum to be represented by the formula $Al_2(SO_4)_3 \cdot 18H_2O$, at which point it solidifies. It is shipped in "ingots" or ground and packed in bags.

Formerly, china clay, a silicate of aluminum, was treated with sulphuric acid to form alum. Since china clay is not readily dissolved by the acid, a siliceous residue remains, which was usually removed; otherwise, the product was known as *alum cake* (see analysis 8, Art. **56**).

54. Iron-Free Alum.—For the best grades of paper, the percentage of iron in alum should be very low. Iron-free alum is made from pure alumina instead of from the crude mineral bauxite.

Owing to the two distinct methods of making iron-free alum and commercial alum, there is a decided difference in the composition of the two products. An alum having as low as 0.2% of reduced iron sulphate, about one-third of which is iron, ought to be good enough to use for the best papers. Frequently, more damage is done to the color of the paper from iron specks that come from the beater bars, or from iron carried by the water, than from iron in alum. Iron may show up as rust spots, or it may affect the color by reacting with the rosin or the dyestuff. Some investigators claim that traces of iron in the size cause color deterioration in paper.

55. Basic and Acid Alum.—Papermaker's alum generally contains an excess of alumina Al_2O_3 over the theoretical quantity to be accounted for in the formula $Al_2(SO_4)_3 \cdot 18H_2O$. Alum containing this excess of alumina is called **basic alum.**

An **acid alum** is one that contains free sulphuric acid in excess of the amount required by the alumina, iron, etc., present. Aluminum sulphate on the market is generally basic to the extent of 0.15% to 1% of alumina; but, for some mill conditions, as, for instance, when hard water is used, an alum of more acid character (up to 0.5% free acid) might be suitable.

56. Alum Analyses.—The following table gives analyses of alum (aluminum sulphate), compiled from several sources, and given by Sutermeister in his "*Chemistry of Pulp and Paper Making.*"

	1	2	3	4	5	6	7	8[1]
Insoluble in water........	.....	0.49	0.06	0.67	0.18	0.4	0.16	20.0–26.5
Alumina, Al_2O_3..........	14.70	16.20	18.81	22.37	16.32	17.4	21.87	12.3–13.0[2]
Iron, Fe_2O_3..............	0.12	0.06	0.80	0.59	0.51	trace	0.40	0.1– 0.2
Zinc oxide, ZnO..........	.....	.....	.....	3.80	......	......	......	....
Soda, Na_2O..............	.....	1.34	0.76	......	0.67	......	0.84	....
Sulphuric acid, SO_3:								
Combined.............	34.60	36.62	45.97	45.28	36.90	39.2	49.27	29.5–31.8
Free..................	0.40	.....	1.03	.....	.....	.....	.....	0.4– 0.1
Water..................	49.95	45.29	32.58	27.34	45.42	43.0	27.46	....

[1] Column 8 gives average composition of alum cake from clay.
[2] Soluble.

THE SIZING PROCESS

SAPONIFICATION OF ROSIN

57. The Original Method of Saponifying.—Early methods of saponifying rosin for sizing followed the general practice of soap manufacture. Rosin was boiled with a solution of caustic soda or soda ash, which contained more soda than was necessary to combine with all the rosin. When finished, the whole was left to stand until the saponified rosin settled out to the bottom, a weak solution of alkali remaining on the top; this latter was then skimmed off. The *rosin soap*, after washing with a strong salt solution to remove coloring matter, was ready for use. This kind of size, known as **neutral,** or **brown, size,** is still used in many mills; it is the most soluble form.

58. Modern Method of Saponification.—It is now more common practice to use size in which the rosin is not completely saponified—one that contains free rosin. It is prepared as follows:

A steel tank, preferably hooded, is fitted with steam coils on the bottom, or with a steam jacket. The use of perforated coils with live steam is undesirable, as it dilutes the solution with water of condensation. Water amounting to from 30% to 100% of the quantity of rosin is used to dissolve the soda. (See Art. **59.**) The amount of water used sometimes causes unexpected complications; but, as a general rule, the smallest possible

amount will give the best results. The following table may be used as an approximate guide:

Per Cent Free Rosin	Per Cent of Water on Basis of Total Rosin Used
25	66 to 75
30	50 to 60
40	35 to 45
45	25 to 35

When the soda solution is heated to the boiling point, the rosin is added. Rosin dissolves quite rapidly in the hot soda-ash solution, and bubbles of carbon dioxide are given off as the rosin reacts with the soda. If the rosin be too finely divided, disagreeable foaming may result.

If the rosin is cooked in an open tank without any provision for taking care of the rising froth, shutting off the steam for a short time will nearly always permit the batch to be finished without any further difficulty. When all the rosin is in, cooking is continued for from 4 to 6 hours, with constant stirring. The course of the reaction can be followed by watching the evolution of gas, which continues to come off as long as there is any uncombined soda ash present.

Certain grades of rosin cause the soap to solidify, partly or completely, before the cooking is finished. This is due to the formation of complex salts of abietic acid, and it may be prevented by melting the rosin before adding it to the hot alkali solution. Size makers observe the way the cooked rosin flows from the end of a paddle. While being cooked, it runs off in long strings; but when the cooking is complete, it breaks off sharply.

Another test is to put a pint of size into a pail, mix thoroughly with a quart of hot water, thin with cold water until the pail is almost full, and then examine for lumps, grains, and sticky particles of free rosin. The cooking should be continued until the size may be diluted into a uniform milky fluid.

59. To Make Size Containing a Definite Per Cent of Free Rosin.—The amount of soda ash used practically determines the percentage of free rosin in the finished size. As an approximate guide to making size containing various percentages of free rosin, the following table, which is based on saponification in alcoholic solution, may be used. The table is calculated for a rosin having an acid value that will neutralize 16% of its weight of

sodium carbonate, leaving 8.8% of rosin that will not saponify in aqueous solution.

SAPONIFICATION TABLE

Rosin (pounds)	Na_2CO_3 (pounds)	Rosin soap (pounds)	Free rosin (pounds)	Total size (pounds)	Per cent free rosin and unsaponified matter
100	16	97.8	8.8	106.6	8.2
100	14	85.5	20.2	105.7	19.1
100	12	73.3	31.6	104.9	30.1
100	10	61.1	43.0	104.1	41.3
100	8	48.9	54.4	103.3	52.6

This table can be corrected for any rosin that has a different saponification value, and it will need correction for water in the finished size.

What happens when rosin is saponified in aqueous solution at atmospheric pressure, is something quite different. The following table gives approximate values, as there is no definite reaction, which varies with the boiling time.

ROSIN	Na_2CO_3	PER CENT FREE ROSIN
100	16	20 to 35
100	14	30 to 35
100	12	35 to 40
100	10	40 to 45
100	9	45 to 50
100	8	50 to 55

Any size containing more than 35% of free rosin must be diluted with an accurately controlled system that has been designed for this purpose; otherwise, the size will decompose, forming a coarse suspension of rosin, which is not only inefficient but certain to cause trouble. The per cent of free rosin does not indicate accurately the tendency toward decomposition, or the solubility of the size. The stability of the diluted size, however, varies directly with the solubility. Much experience is required to determine the degree of solubility required to meet different stock and water conditions.

If the saponification number be known, the chart, Fig. 9, may be used as a guide. The right-hand line of the chart is a

scale of saponification numbers; the right side of the middle line is a scale of free-rosin percentages; the left-hand line has two scales, one giving the pounds of soda ash and the other the pounds of caustic soda that are required for 100 pounds of rosin. To use the chart, lay a straight-edge from the point denoting the saponification number through the point denoting the free-rosin percentage, and its intersection with the left-hand line will give

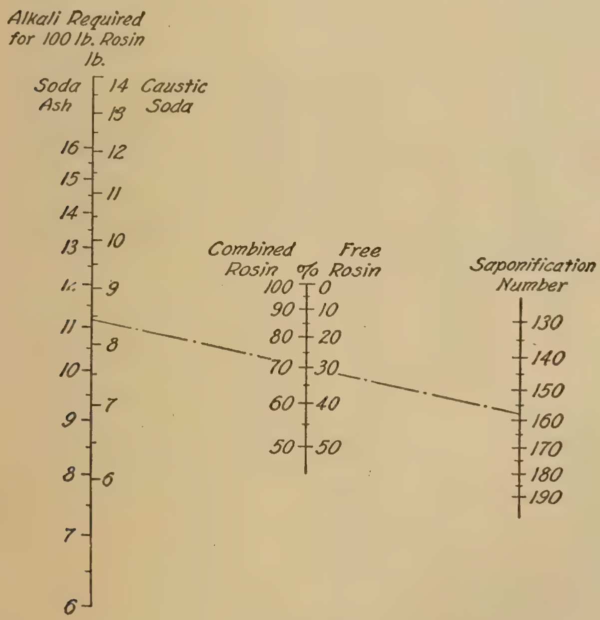

FIG. 9.

the pounds of soda ash or caustic soda required per 100 pounds of rosin. The dotted line shows that if the saponification number is 158, and 30% free-rosin size is desired, $11\frac{1}{4}$ pounds of soda ash or $8\frac{1}{4}$ pounds of caustic soda must be used for each 100 pounds of rosin.

60. Tanks for Cooking Rosin.—The capacity of the tank for cooking rosin should be at least double that required to contain the finished size; otherwise, the tank may foam over. In the open boiler, Fig. 10, provision is made for the froth to flow back into the tank *A* through the bypass *B*; *C* is a steam coil.

In the patented size cooker, Fig. 11, a truncated cone *B* is suspended over the coil *C*. The circulating action through the cone is so rapid that the size can be cooked quickly without boiling over.

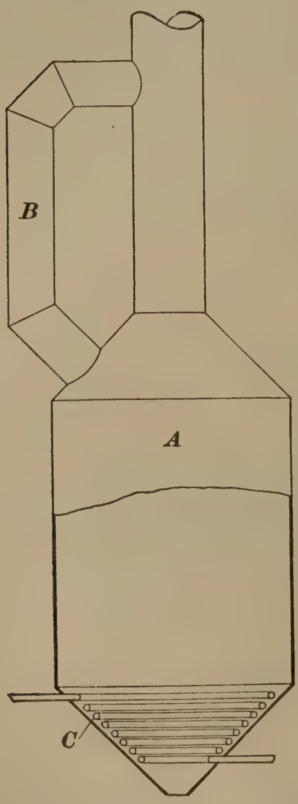

FIG. 10.

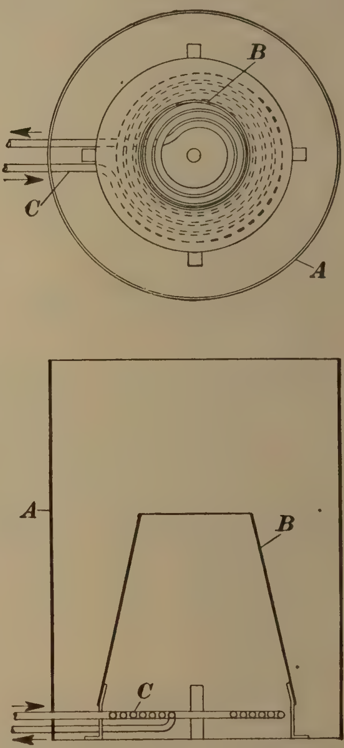

FIG. 11.

According to Arledter, another method of cooking has been advocated in the past and is sometimes used. The size is cooked by indirect steam, under pressure, in a closed tank, Fig. 12, equipped with an agitator *B*, steam coil *C*, water inlet *H*, manhole *M*, and size outlet *N*. Instead of using coils, the lower half of a cooker is sometimes enclosed in a steam jacket.

When cooking under pressure, the temperature can be brought to a point considerably higher than when cooking in an open tank, and the time of cooking is correspondingly reduced. By this

method, the size can be cooked in less than 2 hours, while in the open tank, from 3 to 6 hours are required. In former times, it was the practice to use an open tank, with direct steam, and this necessitated boiling from 6 to 8 hours.

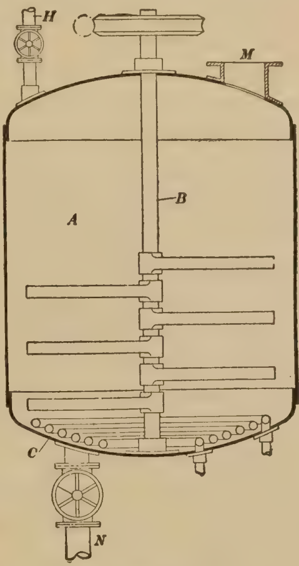

FIG. 12.

QUESTIONS

(1) State briefly the principles underlying the use of rosin sizing.

(2) (*a*) How is rosin obtained and graded? (*b*) What grades are used for sizing?

(3) What is meant by the term *saponified?*

(4) Give the chemical name, the molecular formula, and the characteristics of soda ash.

(5) (*a*) Give the common name for aluminum sulphate. (*b*) When is this substance acid? (*c*) When is it basic?

(6) Explain the process of cooking a batch of rosin size.

(7) How much soda ash should be used for 100 lb. of rosin to make a size having about 30% free rosin?

(8) By what signs can it be determined when the cooking of size is finished?

HANDLING SIZE IN THE MILL

61. Diluting Size.—When size is cooked, it is a thick fluid, which contains from 30% to 40% of water, and is known as **thick size,** or **wax.** Neutral size is so readily soluble, even in cold water, that it is frequently added directly to the beater as *wax* without previous dilution.

With free-rosin size, however, dilution is one of the critical operations in its preparation for use in the mill; and the higher the percentage of free rosin, especially when above 25%, the more carefully must the procedure be controlled to ensure success. When the size carries a considerable proportion of this unsaponified rosin dissolved in the rosin soap, unless the dilution be properly carried out, the free rosin separates in coarse particles, resulting in inefficient or improper sizing and causing trouble on the paper machine.

The thick size must be diluted in such a way as to produce an *emulsion*, with the rosin in a state so finely divided that the particles are practically invisible, except with the aid of a high-power microscope. If proper care be used in carrying out the dilution, even though a high percentage of free rosin may be present, it will not coagulate and separate, and the emulsion will be quite stable. In a clear emulsion, the rosin particles are in what is known as a **colloidal solution** (a colloidal solution is jelly-like, in that the particles are held in suspension in the solution and do not separate from the liquid in which they are suspended), and the rosin is in its most reactive state. When alum is added to such a solution, the rosin is precipitated as though it were a neutral size. If, in the precipitation, the rosin particles are properly attached to the paper fibers, they give the fibers a more water-repellent coating, or they cover a larger fiber surface. If, however, the rosin particles in the solution are not so finely divided as to be invisible, but impart to the solution a curdy or chalky appearance, it indicates that the free rosin is in coarse suspension, and is not in a chemically reactive state.

62. Free-Rosin *vs.* Neutral-Rosin Size.—For some years past, there has raged a very sharp controversy concerning the merits of free-rosin size as against neutral-rosin size, and many arguments have been advanced on both sides. It appears that the fine curd, which adheres to the fibers and gives the paper its water-resistant qualities, is a complex mixture, consisting of rosin, aluminum resinate, and aluminum hydrate, and that no single one of these can be considered as being solely responsible for the sizing result. Both in theory and practice, it is found that the characteristics of this mixture may be notably altered by: (1) varying the conditions under which it is formed; (2) the amount of rosin in the soap; (3) the character of the size emulsion. It is only when these factors are adjusted properly that the most effective results can be obtained.

It is safe to say that high free-rosin size can be so made as to give more satisfactory results than neutral size, and that less size and less alum may be used for the same degree of water resistance. When hard water must be used, this is particularly true, since the calcium salts do not react with the free rosin, but with the soap.

63. Diluting Size.—A size containing about 20% of free rosin may be added directly to the furnish, as is done with neutral size; or it may be diluted to a fairly stable emulsion by stirring into warm water. If it contains more than 20% free rosin, it is unsafe to use thick size this way, since some of the particles may cohere, and show up as rosin spots in the finished paper.

The proper method of using free-rosin size containing 20% to 25% free rosin, is to dilute it to an emulsion containing approximately 2% of solids, and then add this emulsion to the beater. This dilution is accomplished by: (1) adding thick size to hot water, with violent agitation; (2) blowing the size into a tank of hot water in a fine steam jet; (3) adding it in small quantities, while stirring violently. When first made, it is of fairly good character, provided the agitation has been sufficiently violent and the size has not been added too quickly. An emulsion in which the particles have a low melting point, like rosin, tends, when hot, to lose its emulsion character, because the rosin particles agglomerate, and the emulsion gradually becomes more and more curdy. If kept hot for some time, the particles will become so large as to be precipitated, thus spoiling the size.

By *graduated dilution*, a better emulsion can be obtained. This is accomplished by first diluting the thick size to about 25% solids, and then adding, at a boiling temperature, a definite quantity of water, the amount of which will vary in accordance with the free-rosin content of the size. After the size has been so diluted, it will rapidly disperse in cold water.

Other substances might be added to the hot water, or to the size, which would act in such a manner as to protect the size particles from the tendency to agglomerate into larger ones; substances having this property are called **protective colloids,** and they include such materials as glue, casein, and tannic acid. The advantage to be derived from their use depends on the material employed and the conditions under which sizing is performed. The disadvantages are that there is often a tendency to froth, and coloring matter may be introduced that will affect the brightness of the paper.

64. Diluting Systems.—Figs. 13 and 14 illustrate the principle involved in the process of mixing thick, hot size with a small quantity of hot water, at a definite temperature, within an injector, and violently agitating the size and water at the moment they

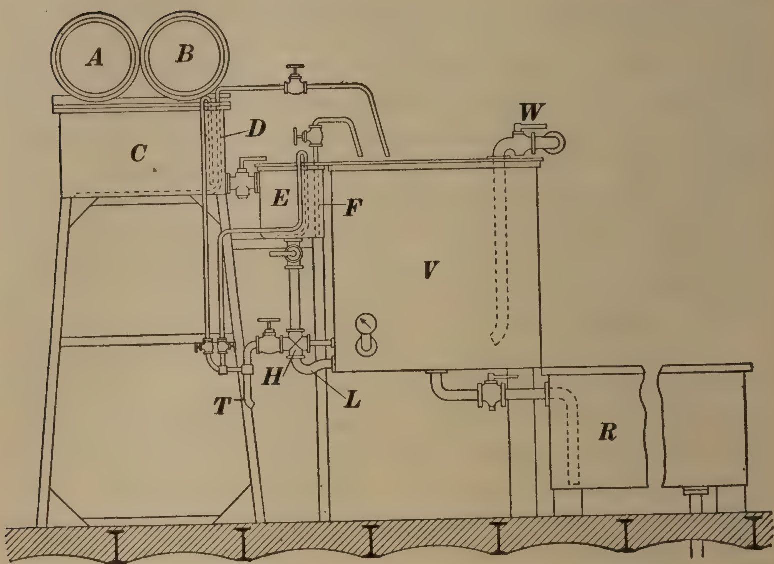

FIG. 13.

A and *B* are barrels of rosin; *C* is a cooking tank, heated by pipe *D*; *E* is a measuring tank; *F* is the heating coil; *V* is the emulsion tank; *H* is a device for mixing heated rosin soap from *E* with water from *V* (through pipe *L*) and steam from *T*, which injects the mixture into *V*; *W* is a connection for supplying water during emulsification: *R* is a storage tank.

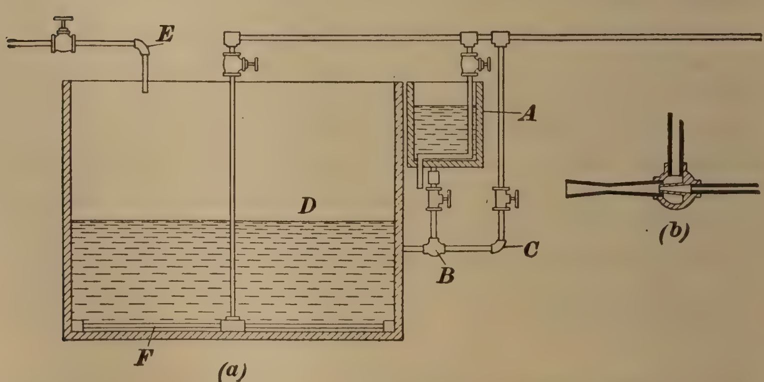

FIG. 14.

The hot size flows from the heated measuring tank *A* into injector *B*; from *B*, it is forced by means of a jet from pipe *C* into hot water in *D*, and some cold water is finally added through *E*. *F* is a perforated steam coil, which heats the contents of *D* and assists in mixing. Details of the injector are shown at (*b*).

mix, by means of a jet of steam. Instantaneous dilution is obtained in this way, and the physical character is preserved by using the same pressure of steam to blow the mixture into a large amount of cold water, which immediately stabilizes the emulsion.

A later development of a size system consists of a pressure tank holding hot size, from which the size is forced directly into a tank containing hot water. This process has some advantages over the steam injector, but there is not much control over the operation; it is used, generally, with a size carrying from 25% to 30% free rosin.

Two older methods for size carrying 25% or less of free rosin are still used occasionally. By the first method, hot size is dropped directly from the cooker into a tank containing twice as much hot water, which is stirred by an agitator; when completely mixed, cold water is added until the correct volume is obtained. By the second method, hot size is fed with hot water into a fan pump, from which it is discharged into a diluting tank.

65. Effect of Hard Water.—A very frequent reason for unsatisfactory sizing results and for the excessive quantity of sizing materials used, is the hardness of the water. If a satisfactory supply could not otherwise be secured, it is probable that a water-softening plant, with proper measures for re-use of white water, would be warranted.

Water used in diluting size should be as soft and pure as possible. A certain degree of deterioration in the emulsion must be expected because of the salts present in the water, which act in a manner similar to alum, precipitating a portion of the size. Salts of lime and magnesia form insoluble soaps (resinates), which produce a thick *scum* on the emulsion tank. This is what happens when size is run into a beaterful of hard water. The same results occur when pearl hardening and chalk are used as filters, as they are both somewhat soluble in water.

66. Furnishing the Beater.—When using diluted size, as above described, it is the general practice to pump it from storage tanks. For measuring the size, the tank should be placed either over the beater or somewhere near, and equipped with a gauge, graduated to show the amount of dry size per unit of depth. With prepared sizes added directly to the beater, directions usually call for a certain number of dippers containing a known amount of dry size.

In sizing a certain kind of paper, it has been noted that 1% of size on the basis of air-dry weight of pulp gave a water resistance of 30 seconds on 35-pound paper (24 × 36—480), 120 seconds on 55-pound paper, and 785 seconds on 78-pound paper. Such data will enable the mill to standardize on definite degrees of water resistance for various weights, and to work out an individual sliding scale of size consumption. The chart, Fig. 15, is a reproduction of one in actual use in a large kraft paper mill, where the beaters hold 1000 pounds of air-dry stock (3.5% consistency), and a 3% size emulsion is used. According to the

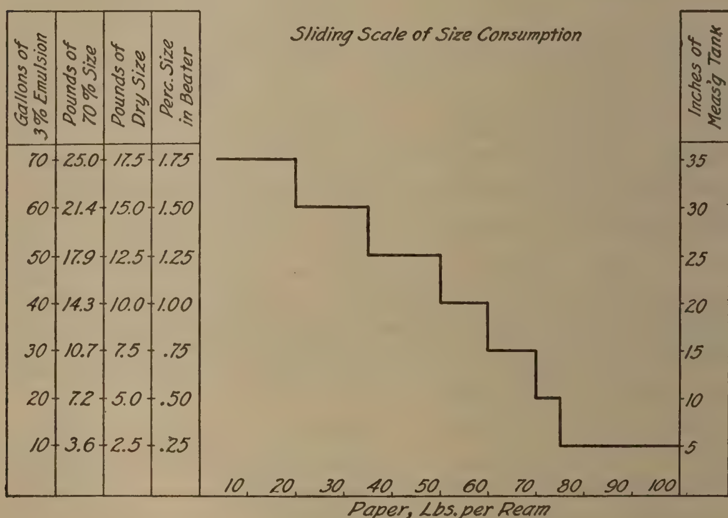

FIG. 15.

chart, a 30-pound paper, for instance, would require 15 pounds of dry size for 1000 pounds of paper, while a 40-pound paper would require 12.5 pounds.

67. Adding Alum.—Although alum is conveniently added in ground form, it is considered better practice to dissolve it first and add it as a concentrated solution. Alum solutions are very corrosive to iron, and should be stored only in wooden or concrete tanks having acid-resistant fittings.

The common form of alum-diluting system consists of a wooden tank, with an agitator; this is worked on a batch (intermittent) system, and is used to dissolve ground alum. The cheapest method is to buy the alum in large cakes, and to keep the tank

(without agitator) filled with them. The tank is also kept filled with water, and a fairly strong solution can be drawn from the bottom, the density of which will vary with the temperature of the water and the time the alum is in contact with the water. Some mills use two tanks, equipped alike, one being used a storage tank, while in the other, alum is being dissolved. By means of hydrometer readings, the solution is kept uniform and adjusted to standards.

PROPORTIONS OF SIZE AND ALUM AND ORDER OF FURNISH

68. Complexity of Reactions.—Sizing is an extremely complex reaction; different combinations occur between the rosin soap and the aluminum sulphate, depending on the excess of aluminum sulphate. The reaction is difficult to control because of the salts, either in the water or the stock, such as carbonates and sulphates in the fresh water, alkali in soda and sulphate pulp, acid in sulphite pulp, and calcium chloride in bleached pulp. These salts are of such varied character that no formula can be given that will apply generally.

Control of hydrogen-ion concentration of the water and the various kinds of stocks, through corrective measures and by thorough washing, will eliminate much of the difficulty. (See Appendix to this Section.)

69. When to Add Alum.—Size is usually introduced before the alum; but there are cases where so many injurious substances are present that the size suffers less injury by following the alum. In such cases, it is presumed that an amount of alum sufficient to combine with the injurious substances, is added in addition to the amount required for the size. When very hard water must be used, or where a considerable amount of alkali is in the paper stock, it is advisable to add enough alum to take care of the hardness, and neutralize the beater before the size is added. In some mills, the size is put in last, just before letting the stuff into the chests, which gives very good results.

70. Amount of Alum Required.—The following table gives a fair indication of the amount of alum required:

Per Cent Free Rosin	Pounds of Alum for 10 Pounds of Rosin
35 to 45	15
20 to 25	20
Neutral	30

These ratios have no basis in theory, because it requires 4 pounds or less of alum for every 10 pounds of dry size; but in practice, good results cannot be obtained unless the alum is in

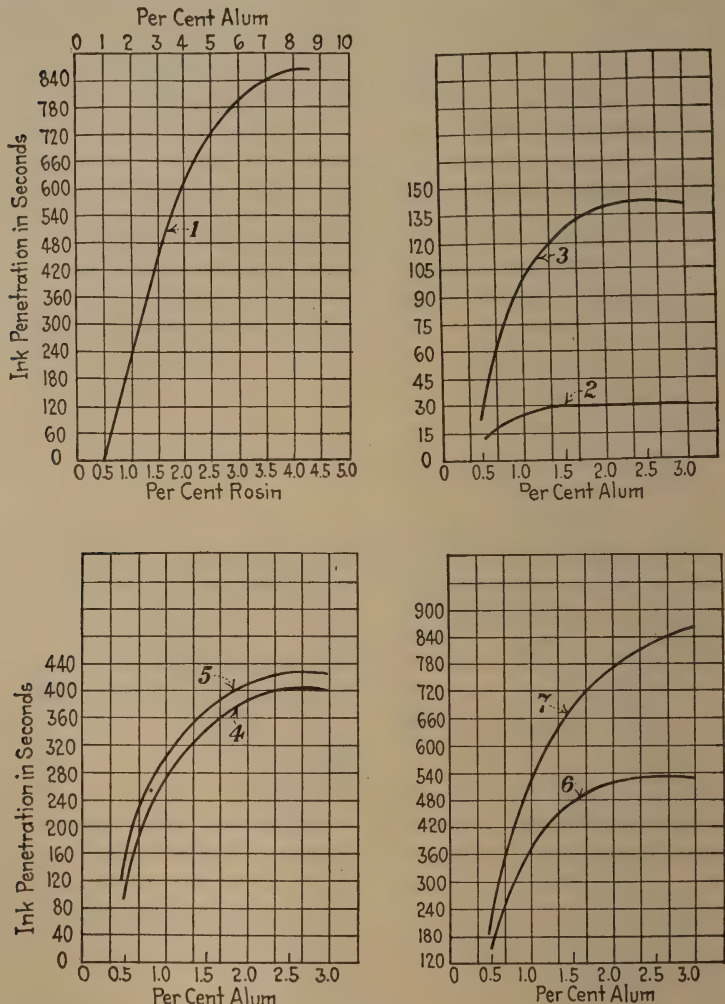

FIG. 16.

excess, and this excess must be greater the more there is of rosin in the form of soap. The table may be used as a guide, but the right proportions of alum and size must be determined for each mill; they will vary with the character of the stock and water,

and methods of reclaiming back water. In this connection, reference should be made to the Appendix on hydrogen-ion concentration at the end of this Section.

Difficulty may be experienced in sizing if steam be used to increase the freeness of the stock, or if the stock become heated through beater or jordaning action.

71. Variation in Water Resistance.—The degree of water resistance that can be obtained in paper by the use of rosin size, depends on the kind and amount of size, method of using it, kind and amount of alum used, temperature and character of the stock and water, degree of mechanical treatment, formation of the sheet on the wire, methods of extracting the water, and manner of drying and calendering.

It was stated in the Section on *Properties of Pulpwood*, Vol. III, that resins oxidize on exposure to sun and air. This accounts for the fact that paper which has been exposed to sunlight gradually becomes less water resistant. What can be accomplished under good conditions of stock and water, using a 40% free-rosin size, is shown in curve 1, Fig. 16, which was presented to the convention of the Technical Association of the Pulp and Paper Industry, held at New York, Feb. 6, 1918, by Paul DeC. Bray. The curve shows that, under good conditions, the maximum sizing effect is obtained with 4% of rosin size and 8% of alum. He also determined the sizing results when using a constant amount of size and varying the alum. Beginning with 0.5% of size on the weight of paper stock, he obtained curve 2, and the other curves, 3 to 7, for each additional 0.5% of size until 3% was reached. Thus, for curve 2, the rosin constant was 0.5%; for curve 3, the rosin constant was 1%; for curve 4, 1.5%, etc. In each case, the ordinates (vertical measurements) give the number of seconds for a standard ink, at constant temperature, to penetrate paper floated on it.

In another mill using the same kind of size and alum, but under different water and stock conditions, the curves showing the sizing results would be different for the same alum ratios. If a size were used containing no free rosin whatever, or if the size were decomposed on diluting, a still different curve would be found, and the maximum result would be lower. Sutermeister points out, in "Chemistry of Pulp and Paper Making," that the loading reduces the sizing effect very materially. Some fillers,

especially those containing calcium salts, affect the sizing more than others.

72. Difficulties in Engine Sizing.—Practical paper makers are constantly experiencing difficulties of a baffling nature in sizing. Attempts to duplicate the successful results of one mill, or to apply the remedies used in other mills for sizing troubles, have been comparative failures. Hydrogen-ion control of the furnish will, no doubt, eliminate many of these difficulties. Seasonal changes in the hardness of fresh water may necessitate a change in the composition of the size, or a change in the customary order of furnish. The temperature of the stock in the beaters, and after jordaning, should be checked at regular intervals: 100° to 110°F. is considered a safe working temperature. Acid, alkali, or bleach residues left in the stock will always affect the sizing, and they should be removed or neutralized before furnishing. Where white water and fillers are used, difficulties may sometimes be experienced from excessive acidity or dissolved salts.

It may be that proper treatment on the paper machine as affecting sizing, is being sacrificed for speed and heat economy. Too much suction on the boxes and couch rolls has a tendency to leave the wire side of the sheet somewhat slack (poorly) sized, and varying pressure across the press rolls, or a defective felt, will cause streaks of varying degrees of water resistance in the sheet. Much more important than this, however, is correct drying on the steam-heated dryers. The best results are said to be obtained if the temperature of the dryers does not exceed 239°F. If this temperature be reached too early or too late, *i.e.*, before incipient fusion, or so-called *sintering*, of the film has occurred, this film will be destroyed by explosive steam passing through it. It is true that loft-dried engine-sized paper is waterproof without sintering of the impervious coating; but it has been shown by mill tests that paper properly dried on steam-heated cylinders will be more impervious to water if the fusion temperature of the rosin is reached while the sheet contains about 50% of water. For the final drying, the temperature should be gradually increased, in order to preserve the impervious coating as much as possible. These conditions are shown by the illustrations (according to Klemm) in Fig. 17.

73. Rosin Spots.—Size should be cool when run into the beater. If suspended free-rosin is in a soft or molten condition when

added to the paper stock, it will not only adhere to the paper fibers but will also gather other particles of rosin and oil or pitch until masses are formed. These masses may cause translucent spots in the paper, or they may retard the operation of the machine by sticking to wires and presses, contributing also to the trouble known as *beater gum.*

It has been suggested that protective colloids be used in the beater to prevent this agglomeration. While this may help in certain specific cases, the general remedy for this trouble is to prevent it by proper emulsifying and diluting methods.

Other rosin spots may come from the natural resins and waxes of wood; from unbleached sulphite fiber, mechanical pulp made

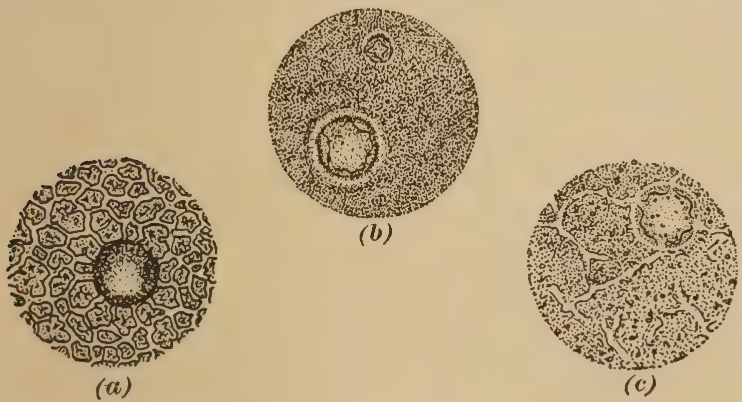

FIG. 17.

Loft-dried paper is shown at (*a*); steam, properly dried, at (*b*); steam, over-dried, at (*c*).

from green wood, or balsam wood not well barked. The pulp pitch is softer than rosin (colophony), and when it causes machine troubles, it can be readily recognized. It usually appears in warm weather, sticking to the wire, press rolls, and felts. It has been shown that the formation of this pitch on the paper machine is governed by the rate of decomposition of alum, and that its appearance in summer months can be prevented by regulating this reaction, either by cooling the stock to 17°C. before the addition of alum, or by adding the amount of acid or acid salt required to bring the pH value below 4.3.

Mildly alkaline salts, such as trisodium phosphate and sodium thiosulphate, called *pitch killers*, are frequently used in the beaters to prevent the accumulation of pitch. A better remedy is to find the source of trouble, and attack it by prevention.

74. Froth Spots.—When the paper stock has a tendency to foam, in consequence of the kind of size used or of impurities in the water or pulp, and when in handling the stock there is a considerable amount of agitation, there is likely to be an accumulation of froth on the screens, and at the slices on the machine. This froth carries in the bubble film a certain amount of fiber, which is liberated when the foam is broken down by the showers. The fiber will be sticky and resinous, and if it gets on the sheet, it will leave a dirty splotch (*froth spot*) on the surface of the paper.

If froth occurs on the machine, the natural reaction of the paper maker is to increase the amount of alum used in the beater. Increased acidity will make the individual froth bubbles smaller, due to the change of surface tension, but it also makes them harder to break up by means of sprays. Study of hydrogen-ion concentration has thrown much light on this phenomenon. It has been found that the tendency of a solution to foam is decreased as the acidity decreases, and as aluminum hydrate and basic sulphate are precipitated. Increasing the hydrogen-ion concentration, *i.e.*, the acidity, by adding more alum will, therefore, actually increase the formation of froth, although it decreases the size of the individual bubbles.

Froth can be prevented from forming by avoiding agitation throughout the course from the beater to the machine; or it can be reduced by altering the surface-tension conditions in the beater furnish. Kerosene, turkey-red oil, or other so-called *froth killers*, are sometimes added to the stock for this purpose, but they are injurious to the sizing. A light froth that does not carry many fibers will cause very little trouble.

Froth is also frequently caused by bleach-liquor residues, or by sulphite waste liquor in the stock. The latter, especially, is very bothersome, and froth caused by it can hardly be broken up by means of water sprays.

75. Color.—It is recognized that rosin will give a yellowish tint to paper, and this must be offset as much as possible by the aid of blue coloring matter. The color effect of rosin becomes noticeable when over 1% of rosin is used.

The strength of direct dyes is helped slightly by sizing, but their shade is dulled, especially if an excess of alum is used. Some of these dyestuffs, however, have a stronger affinity for fibers before they receive their waterproof coating. Size and

alum intensify the shade of basic dyes, because of the formation of color lakes, which are more brilliant in shade and greater in strength of color than the dyes themselves. Acid dyes, which have very poor affinity for fibers, are retained in the sheet by the aid of size and alum. In general, it may be said that, for light tints, dyes should be added *after* size and alum; for deeper shades, a certain quantity of color should be used before sizing, while the final matching and shading must be done afterwards.

76. Strength.—The adhesion of rosin size to paper fibers is greater than the cohesion of groundwood or waste-paper fibers, but is less than the cohesion of sulphite, sulphate, or rag fibers. In the manufacture of strong paper, this bonding effect is important, because the excess of rosin required may reduce the tensile strength of the paper.

77. Finish and Retention.—The finish of paper often depends on the amount of filling material, both the mineral filler and the fine fiber retained in the sheet during its formation on the wire. When the sizing is of poor quality, more of the filling material is lost through the wire, and the weight of the paper is not only less than it ought to be but the wire side of the paper is rough, and it will usually show feathering action when written on with ink. Since it is more difficult to polish a rough surface than a smooth one, the fine material that fills the voids between the larger fibers should be retained.

The hardness of the paper surface depends in part, on the paper stock and its treatment in the beater; but when these factors are constant, it depends on the kind and quality of the sizing materials used. A good quality of high free-rosin size will give a snap and hardness to the paper that cannot be obtained by the use of a neutral or low free-rosin size.

78. Permanency and Rosin Size.—The deterioration and discoloration of paper containing large amounts of rosin size and excess of alum, has been the subject of much speculation and research. While these investigations have not proceeded far enough to justify a definite statement, the following paragraphs represent the current views regarding these phenomena.

Under the influence of air and light, rosin undergoes a chemical change, which causes a yellowing of the paper and also a decomposition of the cellulose. The essential factor in the yellowing

has been found to be soap-like components of rosin with iron, or in the case of bleached papers made from poorly washed stock, to bleach residues.

If the size be extracted from discolored paper with alcohol and ether, the bodies that cause yellowing are removed, and the paper is more or less restored to its original color, thus proving that the rosin sizing is the factor that causes yellowing. As a precaution against the discoloration, the use has been recommended of iron-free alum and rosin in which the iron present has been oxidized by means of chlorine or potassium permanganate.

Although it has not been definitely established that deterioration of engine-sized paper is caused by peroxide of colophony, it is well known that rosin sizing is destroyed by the action of sunlight. Under ordinary atmospheric conditions, engine sizing with rosin is not as permanent as surface sizing with glue, and it should, therefore, not be used for permanent records.

SIZING DIFFERENT KINDS OF PAPER

79. General Statement.—The quantity of size required to impart the requisite degree of water resistance depends on many factors, some of which are: composition of size, the nature of the paper stock, the quality of the paper. Rope, rag, and groundwood require more size than chemical wood pulp. Sulphite pulp, particularly if bleached and thoroughly washed, is easier to size than soda or sulphate pulp, provided no excessive amount of filler be used. Well-hydrated slow stock requires less size than a free one, for any special degree of sizing result.

Beyond a certain limit, the water resistance is not increased by increasing the size, which then seems to be lost in the white water. By changes in the mechanical treatment of the fibers, or by the judicious use of starch, sodium silicate, or glue in conjunction with the size, higher retention of size, and increased water resistance, may be obtained.

80. Writing Papers.—These papers, made almost entirely from rag or sulphite fiber, either alone or in combination, must be sufficiently hard sized to adapt them for pen-and-ink writing. Since they come under the general classification of fine papers, their quality necessitates the use of pure water, and also careful preparation of the stocks. For these reasons, there should be little difficulty in sizing writing papers.

Sulphite bond requires a relatively small percentage, usually $1\frac{1}{2}\%$ to $2\frac{1}{2}\%$ of dry-rosin size, with $2\frac{1}{2}\%$ to 3% of alum being sufficient. Where a good rattle is desired, sodium silicate, starch, or a combination of the two is sometimes used as an adjunct. With the tendency to increase the paper-machine speed, which generally lowers the sizing because of greater stock dilution and more rapid water removal, it is probably necessary to use a higher percentage of size, so that up to 3% is not uncommon. Under exceptionally good plant control, it has been possible to obtain satisfactory results with 0.5% rosin size and 0.75% alum.

Rag stock requires more size than bleached sulphite; so in rag-sulphite bonds, as the percentage of rag becomes greater a larger amount of rosin size is necessary, and it is not uncommon to use as high as 2% or 3%. Because of the long beating time required for rag stock, the pulp frequently gets quite warm, and this tends to injure the sizing. Under such conditions, it is advisable to add the size near the end of the beating operation, or just before the charge is emptied, following with the alum.

Much of the rag-content paper is surface sized with glue or modified starch after engine sizing, to decrease the surface-size requirements. It is important that both sides of the sheet be evenly rosin sized; otherwise, after tub sizing, the sheet will be two-sided as to glue, which will cause curling under variations of relative humidity in the atmosphere.

81. Book Papers.—The chief characteristic of this class of paper is printing quality, which is but indirectly affected by the degree of sizing. A large amount of book paper is not sized, but the average furnish contains probably about 1%. When made from bleached sulphite and soda pulp free from chemical residues, when water conditions are good and the filler used is harmless to sizing, only a very small quantity—0.5% or less—of rosin size will be sufficient for most grades.

Where the short fiber used is from de-inked magazine stock that may contain coated paper, and if calcium carbonate or sulphate is used as filler, there usually is difficulty with the sizing.

82. Coated Stock.—Paper that is afterwards to be coated requires only a moderate degree of sizing, about 1% being the average practice. The sizing, however, must be uniform—neither too little nor too much—and a rather delicate balance must be maintained. Unless sufficiently sized, the paper will

soak up too much of the coating; while if too hard sized, the coating will not adhere with sufficient firmness.

83. Wrapping and Bag Paper.—This class includes an extremely wide range of sizing requirements and practically all kinds of stock in its composition, as well as all degrees of mechanical treatment in its preparation. While practically all grades require a certain degree of water resistance, the amount of size used will probably run from 0.5%, or less, to 3% and 4%, or more. Butcher's wrapping paper and bag paper for certain purposes, are probably the hardest sized. If all sizing conditions are right, about $2\frac{1}{2}$% size should give a fully waterproof result.

In this class can be seen the extent to which hydration of stock affects the water resistance. Unbleached sulphite, well beaten, will have the same sizing effect with 0.5% size as slightly beaten paper from the same stock with 1% or more of size.

When wrapping paper is water finished, regardless of how much size is used, or how water resistant it is before calendering, it is practically impossible to make the paper water resistant, because of the heat and pressure applied at the calenders to the paper while wet.

84. Newsprint.—Standard newsprint paper is now generally made without addition of size. The action of the alum used to coagulate the natural resins and fiber material in the mechanical pulp gives the paper sufficient sizing effect.

In other grades of news, where some filler is used, it is customary to add 0.25% to 0.5% of size to aid in the filler retention and thereby improve the finish. Hanging paper, which is of similar composition, is hard sized, $1\frac{1}{2}$% to 2% size being required.

85. Board.—In the board group, those requiring special water resistance are test liner board for paper cans and oyster pails, and wall board. *Test liner board* is made largely of sulphate pulp, frequently mixed with old papers, and used in the manufacture of shipping containers.

The difficulties in securing uniform and sufficient water resistance can usually be traced to the character of the stock, to insufficient mechanical treatment, high stock temperature in defibering old papers, and bad water conditions.

The board used for making paper cans for carrying cottage cheese, and milk or other liquids, is probably the most difficult

to make satisfactorily resistant to the various products the cans are to contain. Generally, the board is made water resistant with 2% to 3% rosin size; and after the can is fabricated, it is given a paraffin wax coating that will resist the lactic acid or fruit juices. The rosin sizing tends to reduce the amount of wax to be absorbed.

Wall board is made from mechanical pulp or waste paper, or a combination of the two. In order to decrease the tendency toward expansion and contraction under varying conditions of relative humidity, wall board is frequently given a protective, or ornamental, surface coating. To prevent the absorption of moisture from the air, as well as to reduce the penetration of the coating, the stock is usually hard sized; to do this properly, 2% size should be sufficient.

ANALYSIS OF ROSIN SIZE

86. General.—Rosin size consists of a mixture of rosin-sodium soap with various percentages of free rosin and water; it usually contains from 30% to 50% water. This mixture is further diluted to rosin-size milk, which contains from 95% to 99% water.

For purposes of analysis, any barrel or drum of the lot containing size of the same cook, shall be taken as representative of the quality of the size. This barrel or drum is opened, the size thoroughly mixed by careful stirring, and a pint sample enclosed in a fruit jar or, air-tight tin can, so no loss of water can take place between the time of sampling and the test for moisture.

PROCEDURE

87. Moisture and Total Solids.—Weigh out 20 to 25 grams of the size in a tared 150-c.c. beaker, and dissolve in hot water. This is best accomplished by first heating the size until it starts to melt, and then adding hot water in small portions until the size is all dissolved. While being dissolved, the size should be stirred constantly. When the size is in solution, transfer it to a beaker containing 200 to 250 c.c. of hot water, and mix thoroughly; finally, transfer it to a 500-c.c. volumetric flask. Cook for a few minutes, and dilute to 500 c.c.

Measure 50-c.c. portions into weighed crystallizing dishes of about 100-c.c. capacity, and evaporate to dryness in an oven

at 105°C., to constant weight. If the acid number be desired, the evaporation should not be over night, since it has been found that prolonged drying materially alters the acid number. The difference between the amount (per cent) of total solids and 100 per cent is the per cent of moisture in the sample.

88. Total Rosin.—Measure 50 c.c. of the original size solution into a separatory funnel and acidify with 10 c.c. of dilute (1%) sulphuric acid. Add 50 c.c. of ether, shake well, and allow to stand until the two layers are completely separated. Draw off and wash the ether layer with 25-c.c. portions of water; draw off the water into the second funnel, and pour the ether extract into a weighed Erlenmeyer flask. Rinse the first funnel with 25 c.c. of ether into the second funnel. Shake well, and draw off the water layer into the second funnel. Wash as above with 25-c.c. portions of water. Repeat once more. Evaporate the ether from the combined extracts as in the free-rosin determination (Art. **88**). Dry to constant weight at not over 105°C. Calculate the per cent on a dry basis, and multiply by 100 to obtain the per cent of combined rosin.

In this case, the ether need not be especially purified, though it should be as free as possible from any non-volatile residue.

89. Free Rosin.—To about 5 grams of the size, accurately weighed into a 150-c.c. beaker, add 10 c.c. of neutral 95% alcohol; mix thoroughly by stirring the mixture. Transfer the solution to a 250-c.c. separatory funnel, using 30 c.c. of cold distilled water for rinsing the beaker. Rinse out the beaker further with 40 c.c. acid-free ether, and transfer to separatory funnel. Shake vigorously for about 1 minute. The separation will be almost immediate, and no emulsion will form. Cool under tap before removing stopper, to prevent loss. Draw off the lower layer into a second separatory funnel, and run ether into a third separatory funnel. Add 20 c.c. of acid-free ether into the second separatory funnel, and shake vigorously about 1 minute. In a minute or two, the soap solution can be drawn off into the first separatory funnel and the ether added to the first ether in the third separatory funnel. Repeat this same process with two more 20-c.c. portions of acid-free ether, combining the ethers in the third separatory funnel. Wash the combined ether extracts with three 15-c.c. portions of distilled water, and run the ether

into a weighed flask. The ether is then distilled off through a condenser. Dry the flask to constant weight at 100° to 105°C.

NOTE.—It is important that the ether used in this determination be especially prepared by washing once with Na_2CO_3 solution, and then sufficiently with water. It should be tested with a moist piece of sensitive litmus paper, which should not change color when completely submerged in the ether for 15 minutes.

90. Free Rosin by Titration or Acid Number.—Take the residue from the moisture determination and dissolve in 95% alcohol, heating until everything is in solution. Titrate with N/10 alcoholic potash (Art. 49), using phenolphthalein as indicator. One cubic centimeter of N/10 alcoholic potash equals 0.0346 grams of rosin; this is the value given by Allen and Lewkowitsch, though Sutton states it is 0.0329 gram. The percentage of free rosin is calculated on basis of dry matter present, and not on the weight of total sample.

91. Total Alkali and Ash.—Weigh approximately 1 gram sample of size into a platinum crucible; ignite at moderate temperature under hood until all carbonaceous matter is burned off; then cool and weigh. Let W = weight obtained. Then,

$$\frac{W}{\text{Weight of sample}} \times 100 = \text{per cent of ash.}$$

Dissolve ash in water, and titrate directly with N/10 acid, using methyl orange as indicator. Calculate the titration to Na_2O.

1 c.c. N/10 acid = 0.0031 gram Na_2O = 0.0053 grams Na_2CO_3

This result should check the result found for ash per cent reasonably close, unless the size contain insoluble or other foreign matter.

92. Free Carbonate.—Dissolve about 10 grams of free-rosin soap in a little water, and shake in a separatory funnel with an amount of neutral sodium chloride sufficient to leave a residue undissolved. Now open the stopcock carefully and allow the solution to run into a second separatory funnel, the undissolved salt serving as a filter. Wash the soap remaining in the first funnel with a saturated solution of neutral sodium chloride, and add the wash solution to the solution in the second funnel. The solution that has been allowed to run into the second separatory funnel contains free alkali, but no free rosin. Next add to the

contents of each funnel 30 c.c. of N/10 acid, shake well, and titrate each solution with N/10 alkali solution. If n c.c. of alkali is required, then the value for free alkali in the soap is

$$(30 - n) \times 0.0053 \text{ gram of } Na_2CO_3.$$

NOTE.—If it be desired to determine the free alkali in the diluted solution, solid sodium chloride may be added until there is an excess of undissolved salt, and then the procedure may be as in the foregoing method.

93. Free Carbonate: Optional Method.—Weigh out 10 grams of size and dissolve in 200 c.c. of acid-free absolute alcohol. Let the solution stand 8 to 10 hours, or over night if possible, protected from acid fumes and moisture. Filter on a weighed dry filter, and wash thoroughly with absolute alcohol. Pour at boiling temperature through the filter, and after cooling, titrate the aqueous solution with N/10 acid and methyl orange. Calculate to Na_2CO_3.

$$1 \text{ c.c. N/10 acid} = 0.0053 \text{ gram } Na_2CO_3$$

NOTES.—(1) The filter need not be weighed if the insoluble matter is not to be determined.

(2) The determination of free alkali by this method is subject to a slight error on account of the solubility of Na_2CO_3; when allowed to stand 16 hours in 200 c.c. of 95% alcohol, 0.0075 gram went into solution. In the case of absolute alcohol, 0.0050 gram dissolved. With 10 grams of ordinary rosin size and 200 c.c. of absolute alcohol, the moisture in the size dilutes the alcohol to about 95%, and the solution of Na_2CO_3 would cause the result to be 0.07% too high. Consequently, this figure may be used as a negative correction when greater accuracy is desired.

ROSIN-SIZE MILK

94. General.—Rosin-size milk usually contains about 98% water and 2% rosin. For general work, the determination of total solids is sufficient.

95. Procedure.—Total solids: Pipette 25 c.c. of rosin-size milk into a weighed platinum or glass dish; evaporate to dryness over water bath, then dry to constant weight at 105°C., cool in a dessicator, and weigh.

96. Inert Free Rosin.—If the milk appears to contain suspended rosin that settles on standing, boil 300 c.c. for 30 minutes, filter on a filter paper that has been dried at 100°C. and weighed. Wash with hot water and weigh the dried residue.

97. Free Rosin and Total Rosin.—If free rosin and total rosin are desired, the same procedure as previously used for analysis of rosin size may be followed.

NOTE.—If difficulty may be experienced with emulsions, add 5 to 10 c.c. of neutral grain alcohol.

APPENDIX

HYDROGEN-ION CONCENTRATION

BY H. L. JOACHIM, PH. D.

PRELIMINARY EXPLANATIONS

98. Electrolytic Dissociation.—Atoms are held together in molecules as the result of the action of electric forces. When certain substances dissolve in water, some of the molecules are divided into particles called **ions;** and some of the ions carry charges of positive electricity, while others carry charges of negative electricity. The sum of the positive charges is equal to the sum of the negative charges. This separation into ions is called **electrolytic dissociation,** and substances that behave in this manner are called **electrolytes.** An electrolyte is also defined as a substance whose solution will conduct an electric current; thus, a solution of salt $NaCl$ is an electrolyte, but a solution of sugar $C_{12}H_{22}O_{11}$ is not. The ions in a salt solution are Na^+ and Cl^-. The signs $+$ and $-$ indicate that one sodium ion carries a one-unit charge of positive electricity, and that one chlorine ion carries a one-unit charge of negative electricity.

Molecules of water dissociate very slightly into hydrogen ions H^+ and hydroxyl ions OH^-; that is, when an electric current is passed through water, some of the molecules are found to be resolved into ions, according to the equation $HOH = H^+ + OH^-$. These ions are characteristic, respectively, of acid and alkaline (basic) solutions; but since the number of acid ions equals the number of basic ions, the solution is neither acid nor basic, and is termed **neutral.**

99. Some electrolytes, however, produce an excess of either hydrogen or hydroxyl ions, and the solution is acid or alkaline, according to whether the H-ions or OH-ions are in excess, respec-

tively. Thus, hydrochloric acid HCl in solution produces H^+ and Cl^-; here there are no OH-ions (except those from the water) and there is an excess of H-ions. A solution of sodium hydrate $NaOH$, a base, gives Na^+ and OH^-, and there is an excess of OH-ions. The first solution is strongly acid and the second is strongly alkaline.

When a salt is dissolved in water, several reactions may take place. For example, sodium chloride in solution gives Na^+ and Cl^-; the former may react with the hydroxyl of the water to form the base $NaOH$, while the latter reacts with the hydrogen of the water to form the acid HCl. Since both these substances, the acid and the base, dissociate practically to the same extent, the resulting H-ions and OH-ions are practically equal in number, and the solution remains neutral. But sodium acetate CH_3-$COONa$ in solution gives Na^+ and CH_3COO^-, and these ions combine with OH^- and H^+ (from the water) to form $NaOH$ and CH_3COOH (acetic acid). The $NaOH$ dissociates very largely, and produces a large number of OH^- ions; while the acetic acid dissociates but slightly, producing only a few H^+ ions; the solution, therefore, contains an excess of OH^- ions, and is alkaline (basic). Again, aluminum sulphate (papermaker's alum) in solution produces the opposite result. Thus, $Al_2(SO_4)_3$ becomes $2Al^{+++} + 3SO_4^{--}$, aluminum being a triad and SO_4 a dyad in their chemical reactions; hence, the Al ion carries three charges, and the SO_4 ion two charges, as indicated by the number of signs, the total number of unit charges for each being the same, or 6. Some of the Al^{+++} ions unite with OH^- ions to form aluminum hydrate $Al(OH)_3$, and some SO_4^{--} ions unite with H^- ions to form sulphuric acid H_2SO_4. Sulphuric acid dissociates much more completely than aluminum hydrate; the solution, therefore, contains an excess of H^+ ions, and is acid. For this reason, though not in the strict chemical sense, alum is often called an *acid salt*.

The degree of acidity of a solution is proportional to the numerical excess of hydrogen ions; and the degree of alkalinity is proportional to the numerical excess of hydroxyl ions.

100. The *concentration* (relative number) of hydrogen or hydroxyl ions determines the effective acidity or alkalinity of a solution. The application of the measurement of hydrogen-ion concentration in the several steps of the manufacture of pulp and

paper, making possible a closer control of stock and water conditions, has resulted in considerable savings of raw materials, the remedying of some manufacturing troubles, and greater uniformity of the finished product. The literature on this subject is widely scattered, and is, usually, of a highly technical nature. The present treatment is a brief résumé of the principles involved, and of the present status of its applications in pulp- and paper-making processes. For further details, the student should consult the bibliography at the end of this Appendix.

101. Effective Acidity or Alkalinity.—The usual methods of determining acidity or alkalinity by titration with standard solutions, express the total acid or base present, irrespective of the degree of dissociation. Measurement of the hydrogen-ion concentration determines the effective or true acidity or alkalinity. Clark refers to *normality* in its usual sense (in titrating) as the *quantity factor* of acidity, and to the hydrogen-ion concentration, as the *intensity factor*. The former is the total quantity of available acid; the latter represents the real intensity of acidity whenever it is the hydrogen ion that is the more directly active participant in a reaction. In a solution, there are always hydrogen and hydroxyl ions in definite relation to each other; hence, by measuring one (the hydrogen ion, say), both effective acidity and alkalinity are determined.

The usual manner of expressing hydrogen-ion concentration is in terms of the pH number, which will now be explained. In what follows, hydrogen ions H^+, and hydroxyl ions OH^-, will be respectively expressed as H-ions and OH-ions.

102. The pH Number.—Pure water dissociates slightly into equal numbers of H-ions and OH-ions (*i.e.*, it is neutral), and because of this dissociation, it is a conductor of electricity, in other words, an electrolyte, though a very poor one.

According to the so-called Law of Mass Action,

$$\frac{\text{conc. of H-ions} \times \text{conc. of OH-ions}}{\text{conc. of undissociated water}} = \text{a constant}$$

As evidenced by its poor conductivity, the concentration of the undissociated water is relatively very high, and may be considered a constant. Consequently, the above equation may be written,

$$\text{conc. of H-ions} \times \text{conc. of OH-ions} = \text{a constant}$$

By electrical conductivity measurements, this dissociation has been found to be $\frac{1}{10,000,000} = 10^{-7}$ mols[1] per liter each of hydrogen and hydroxyl ions (*i.e.*, in 10,000,000 liters of water, there would be 1 gram of hydrogen and 17 grams of hydroxyl ions).

A *normal standard solution* in titration is one that contains 1 combining weight (in grams) of the active substance in 1 liter of solution; similarly, a solution is said to be of normal strength with respect to hydrogen ions when it contains 1 *gram of ionized hydrogen per liter.* From this, it will be seen that water is an extremely weak solution with respect to hydrogen-ion concentration. But this method of designating H-ion concentration is very inconvenient to use—the numbers are so small as to be unwieldy and difficult to handle. Sörenson therefore suggested the term pH, which may be defined as the *logarithm of the reciprocal of the H-ion concentration*, or,

$$\text{pH} = \log \frac{1}{\text{H-ion concentration}}$$

In the case of pure distilled water, there is 0.0000001 gram of ionized hydrogen per liter, and the pH value for water is

$$\log \frac{1}{0.0000001} = \log 10,000,000 = 7$$

This value, 7, is the neutral point on the pH scale, which will now be explained.

103. Note.—For those students unfamiliar with the use of logarithms, it may be stated that any number may be expressed as a power of 10. Thus, $1 = 10^0$; $10 = 10^1$; $100 = 10^2$; $1000 = 10^3$; etc. For any number between 1 and 10, the exponent is a decimal fraction, an unending decimal; for a number between 10 and 100, the exponent is 1 plus a decimal; for any number between 100 and 1000, the exponent is 2 plus a decimal; etc. These exponents are called **logarithms**; thus, log 2 means "the exponent of 10 that makes the expression equal 2." To 7 places of decimals, this exponent is .3010300; that is, $10^{.30103} = 2$, and the logarithm of 2, written log 2, is .30103. The logarithm of 20 = log (2×10) = log. $10^{.30103+1} = 1.30103$; because, according to the law of exponents in algebra, $10^{1.30103} = 10^1 \times 10^{.30103}$, just as $4^5 = 4^2 \times 4^3 = 4^{2+3}$. But $10^1 = 10$; $10^{.30103} = 2$; hence, $10^1 \times 10^{.30103} = 10 \times 2 = 20$. In the same manner, log 200 = 2.30103, log 3000 = 3.30103, etc. From this, it will be seen that increasing the logarithm (exponent of 10) by 1, multiplies the number by 10; decreasing the logarithm by 1, divides the number by 10, etc.

[1] A mol is the number of grams equal to the sum of the atomic weights of the element or group of elements in question; as 1 mol of SO_4 is 96 grams.

104. The pH scale for expressing acidity and alkalinity can be illustrated by a comparison with the Fahrenheit thermometer scale.[1] On the Fahrenheit scale, the 32° mark represents the freezing point of water. For present purposes, assume that values above 32° represent degrees of heat, while values below 32° represent degrees of cold. Thus, any values higher than 32°, as 34°, 36°, 40°, etc., denote an increase in heat, the degree of heat *increasing* as the numbers *increase;* and any values below 32°, as 30°, 28°, 20°, etc. denote an increase in coldness, the degree of coldness *increasing* as the numbers *decrease.*

In a similar manner, the degree of acidity or alkalinity of a solution is expressed by the H-ion, or pH, scale, only instead of being called degrees (as on the thermometer scale), the graduations indicate pH values. Evidently, it is unnecessary that a person shall know the derivation of the term "degree Fahrenheit" in order to determine the temperature of a solution; and it is equally unnecessary that he know the derivation of the "pH

ACID NEUTRAL ALKALINE

←——————————————————————→

etc. 5.6, 5.8, 6.0, 6.2, 6.4, 6.6, 6.8, **7.0,** 7.2, 7.4, 7.6, 7.8, 8.0, 8.2, 8.4., etc.

FIG. 18.

value" in order to use this to measure the acidity or alkalinity of a solution. On the H-ion scale, a value of pH 7.0 represents neutrality; that is, a solution having a pH of 7.0 is neither acid nor alkaline.

Continuing the comparison of the two scales, on the pH scale, any values higher than 7.0, as 7.2, 7.4, 8.0, 10.0, etc., denote alkalinity, the degree of alkalinity *increasing* as the numbers *increase;* also, any values lower than pH 7.0, such as 6.8, 6.6, 6.0, 4.0, 3.5, etc., denote acidity, the degree of acidity *increasing* as the numbers *decrease.* This will be clear from the diagram, Fig. 18.

A pH value is, therefore, simply a number denoting the degree of acidity or alkalinity of a solution; in a few days, an operator will learn to use this term just as intelligently as he does the term *degree Fahrenheit.* For example, suppose a solution has a pH value of 7.6; the solution is thus slightly alkaline. If another solution has a pH value of 8.2, it is more alkaline than the one of pH 7.6. It is clear, therefore, that an acid, or acid-reacting salt, such as alum, must be added to a solution of pH 8.2 in

[1] W. A. Taylor, *Pulp and Paper Magazine,* Nov. 24, 1927.

order to supply sufficient H-ions to bring the pH value of the solution down to 7.6; still more must be added to bring it down to the neutral point of 7.0; and more yet to give it an acidity value of pH 6.6, 5.8, etc. Similarly, if a solution has a pH value of, say, 6.0, it is necessary to add to it an alkali, such as lime or soda ash, in order to bring the solution to the neutral point, or pH 7.0; and still more must be added to bring it to an alkalinity of, say, 8.0.

Remembering that a pH scale is a scale of logarithms, then in accordance with Art. **102,** an increase of 1 unit in the scale increases the alkalinity 10 times, while a decrease of 1 unit increases the acidity 10 times. Thus a solution of pH 5.0 has 10 times the effective acidity of one whose pH is 6; and a solution having a pH of 8.4 has 10 times the effective alkalinity of one whose pH is 7.4.

105. Comparison of pH and Titration Values.—The following table shows the approximate relationship between total acidity and total alkalinity, as determined by titration, and effective acidity and effective alkalinity, as determined by hydrogen-ion measurements, of some acids and bases. These solutions contain the same amounts of hydrogen or hydroxyl, but not the same amounts of H-ions and OH-ions.

N/10 Acids	pH Value	N/10 Bases	pH Value
Hydrochloric acid	1.0	Aniline	7.8
Phosphoric acid	1.5	Sodium bicarbonate	8.4
Acetic acid	2.9	Borax	9.2
Carbonic acid	3.8	Ammonium hydrate	11.3
Boric acid	5.2	Sodium carbonate	11.6
Phenol (carbolic acid)	6.5	Sodium hydrate	13.1

METHODS OF DETERMINING pH VALUES

106. Indicators.—In many cases, pH determinations are made by means of **indicators,** which are dyes that change in color when they are acted upon by solutions of different degrees of active acidity or alkalinity. Each indicator has *its own definite pH range,* and the fact that these ranges overlap usually permits the checking of the results found by using one or two other indicators. This statement will be clearer after examining the following table, which gives the pH ranges for the indicators most used. These indicators have each two limiting colors, the solution gradually

changing color from one limit to the other as the acidity or alkalinity of the solution changes.

TABLE OF INDICATORS

Name	pH Range	Color Change
Meta cresol purple	1.2 to 2.8	Red to yellow
Bromphenol blue	3.0 to 4.6	Yellow to blue
Bromcresol green	4.0 to 5.6	Yellow to blue
Chlorphenol red	5.2 to 6.8	Yellow to red
Bromthymol blue	6.0 to 7.6	Yellow to blue
Phenol red	6.8 to 8.4	Yellow to red
Cresol red	7.2 to 8.8	Yellow to red
Thymol blue	8.0 to 9.6	Yellow to blue
Nitro yellow	10.0 to 11.6	Yellow to orange
Sulfo orange	11.0 to 12.6	Yellow to orange

Each indicator has, of course, its own color change. Thus, bromthymol blue is yellow at pH 6.0, and is deep blue at pH 7.6; chlorphenol red is yellow at pH 5.2, and is deep red at pH 6.8; etc. By adding solutions of these indicators to separate test tubes of the material that is to be tested, and then comparing the color obtained with the color standards for the various indicators, the pH value can be read off directly from the standards.

Outfits for applying these tests are on the market, two of which will be described here. Of course full directions for its use accompany each outfit.

107. Block Comparator.—A widely used outfit for measuring the pH number consists of a wooden case containing any one set of color standards (9); four graduated test tubes of 10-c.c. capacity, all of the same bore and thickness; a 50-c.c. bottle of the indicator solution corresponding to the color standards; and a 0.5-c.c. pipette and nipple for measuring out the solution.

When testing clear and colorless solutions, one of the test tubes is filled to the mark with the solution to be tested, and 0.5 c.c. of the indicator solution (which has previously been found by rough determination to cover the range) is added to it by use of the pipette. The test tube is then placed in the hole in the block part of the middle slot. Color standards are placed in the holes on either side of the test tube (there are two rows of three holes each, with the test tube in the middle one), and the standards are changed until an exact match is obtained for the color of the solution in the test tube, or until the shade of color of the sample being tested lies between the colors of two standards whose pH

values differ by 0.2 pH. Either of these may be taken as the pH value of the sample, or the value may be taken half way between them.

When the liquid to be tested is colored or turbid, three of the test tubes are filled to the mark with the liquid, and are placed in the three holes back of the slots. To the middle tube, 0.5 c.c. of the indicator solution is added. A tube of distilled water is then placed in front of the middle tube, and color standards are placed in holes in front of the other two tubes containing the sample, changing these until a color match is obtained. By this means, the effects of color and turbidity are partially eliminated.

In collecting the sample to be tested, care should always be taken to ensure that it is representative of the entire batch. For instance, when sampling a beater, the stock should be allowed to turn around twice while small samples are being taken at regular intervals. These samples are combined and filtered into the test tubes through a piece of machine-wire screen (60-mesh), which is fitted to the walls of a glass funnel. Where the alum is dissolved, the sample may be taken about 10 minutes after adding the solution to the beater; while intervals of 20 to 25 minutes should be allowed where dry alum is used. If the optimum (best) time for sampling has once been determined, it should be strictly adhered to, since variations in time will affect the test to some extent. The results of a series of tests made in this manner on kraft stock were as follows:

	pH
Stock in beater	7.7
After adding 20 pounds of silicate of soda	7.9
After adding 15 pounds of size, 30% free rosin	8.0
After adding 22 pounds of alum, dry	4.9
White water from machine	5.7
Fresh water to beater and machine	7.3

108. Double-Wedge Comparator.—This is another colorimetric apparatus for making rapid and moderately accurate determinations of hydrogen-ion concentration. Under ordinary conditions, the readings are accurate to about 0.05 of a pH unit when clear and colorless liquids are being tested, and to 0.1 of a pH unit when the solution is colored or turbid.

The double-wedge comparator prism is composed of two wedge-shaped pieces. These are colored, one with the acid color of

some indicator dye, and the other with the alkaline color of the same dye. The two wedges are so placed in their relation to each other that a beam of light in passing through the prism, goes first through one prism and then through the other. This gives a resultant prism, one end of which is the acid color of the indicator, while the other end has the alkaline color of that dye, the middle parts varying markedly in color from one end to the other. The exact color value of these dyes is accurately known for various hydrogen-ion concentrations, and a scale is attached to the prism, which gives the acidity (or alkalinity) units in pH units and specific acidity units.

Readings are made by placing a small amount of the sample in a test cell, and adding a drop of standard indicator solution. After being carefully mixed, the color in the test cell is compared, by means of a comparing block, with the standard prism; and when the prism has been moved to such a position that the colors are the same, the reading of the hydrogen-ion concentration can be found on the scale. The size of the test cells, the color depth of the prism, and the concentration of the indicator solution are all arranged in such a manner that a single drop of dye added from a standard-size dropper to one test cell of the liquid being tested (1 c.c.), will give exactly the correct intensity of color.

While these colorimetric determinations of H-ion concentration appear simple, the extreme sensitiveness of the indicators makes it essential that the operator be experienced in this form of test, and that he appreciate the need of close attention to detail. Carelessness or ignorance may render the observations valueless, as a number of factors may interfere with the accuracy of the determination.

109. Electrometric Method.—The colorimetric method, just described, is more often used in pulp- and paper-mill work. The electrometric method, which is more accurate, is also used, but requires special apparatus and a more highly trained operator; it will be only briefly touched on here.

This method measures the electromotive force, or voltage, that is developed at suitable electrodes that have been immersed in electrolytes, solutions that dissociate into positive and negative ions. In the usual arrangement, one electrode is called the *hydrogen electrode*, and the other the *calomel electrode* (when it consists of a saturated solution of calomel—mercurous chloride),

and the solution to be tested is placed between them. The electrical instrument connections are made to the positive and negative terminals. The hydrogen electrode usually consists of a piece of platinum wire or foil, coated with platinum black. The course of the circuit is from the electric cell, through a wire to the hydrogen electrode, into and through the solution being tested, out through the other electrode through the measuring instrument, and back to the cell. When in use, the electrode is kept saturated with hydrogen, which is admitted under light pressure. The voltage developed at the contact of the electrode and solution bears a definite relation to the concentration of hydrogen ions in the solution.

Various forms of hydrogen electrodes have been described in the literature. When solutions vary in pH from 2 to 8, the quinhydrone electrode gives very accurate results; and when the pH varies from 5 to 14, the bare tungsten electrode is the better. In either case, the other half of the cell is a saturated calomel electrode. There has also been some promising work done with cadmium electrodes, which have a wide application, particularly for use in connection with sulphite liquors.

Because of special conditions, such as polarization and fall of potential through the solution, an ordinary voltmeter is unsatisfactory for measuring the voltage between the electrodes. The potentiometer has come into general use in making hydrogen-ion measurements; it is made in various forms by the manufacturers of apparatus to measure H-ion concentration. There is also on the market what may be called a *vacuum-tube* voltmeter, employing radio principles, which may be used in conjunction with any of the common electrodes to give continuous and direct pH values.

APPLICATIONS TO PULP AND PAPER INDUSTRY

110. Water Purification.—The quality of the water available is often a grave problem for a paper mill. A water of good quality is a necessity, since it will eliminate difficulties throughout the entire process. In cases where pure water cannot be obtained many mills have found it necessary to install their own purification plants. There are few, if any, waters to which pH control cannot be advantageously applied in their purification. This control is of most importance in connection with coagulation to

remove color and turbidity. The best coagulation occurs at definite pH values, the value being different for different waters, depending on the color, turbidity, natural alkalinity, temperature of the water, change in source of supply, etc. The optimum (best value) for water in any locality may vary from 4.2 to 7.8; it is necessary, therefore, to determine the optimum for each individual water, and with reference to the process in which the water is to be used. The hydrogen-ion condition of paper stock is almost entirely that of the water that carries the fibers, but is also affected by the pH of the pulp and the nature of the dissolved salts that may be added.

A sample of water may be tested by adding increasing weights of alum (in solution) to equal portions of the water, and noting the rapidity of coagulation and settling. The alum produces a flocculent precipitate of aluminum hydrate, which entangles the suspended matter.

111. White Water.—Another point at which pH control is of value is in the recovery of valuable materials from the white water. According to conservative estimates (1928), the loss of valuable materials in white water throughout the United States amounts to about $25,000,000 per year. It is also estimated that, by proper recovery methods, this loss can be reduced to less than $5,000,000. As salvage of fiber and filling materials is largely dependent on coagulation and settling or filtering, just as with fresh water purification, the importance of pH control is apparent. Some mills are getting good results at pH values varying from 4.2 to 5.0; but, as in fresh-water purification, no definite optimum can be given, as it will vary for different mills.

112. Rag Washing.—In washing rag stock, as in the case of wood pulp, hydrogen-ion concentration is of importance; but it should be established according to prevailing conditions. For instance, rags cooked with alkali could be washed to a lower pH value for the water than wood pulp cooked with acid. It is considered good practice to wash the stock to the desired pH value, and then store in reasonably dry condition.

113. Control of Beater Conditions.—All stocks going to the beater should have the same pH value; this helps in maintaining uniform conditions in the beater. This effect can be secured after the pulp is washed, by adding soda ash or caustic soda to

sulphite pulp and other acid-reacting stock, and by adding sulphuric acid (or alum) to soda pulp, rag stock, and recovered waste papers. The stocks will then blend with no (or a minimum of) chemical interaction, and the beater condition will be fundamentally correct for sizing and coloring. It must be remembered, however, that pH value, while very important, may not be more important than the kind of electrolytes present. For example, sodium sulphate would have no great effect on either sizing or coloring, but calcium sulphate might have a decidedly injurious effect on both.

Hydrogen-ion control of paper making originated in the beater room, where it is of the greatest importance in controlling the acidity of the stock in engine sizing. To what extent the progress of the beating action depends on the pH of the stock, has not as yet been definitely established, but it has been possible to effect savings of alum and size by keeping the pH constant.

114. Pulp Washing.—The washing of pulp can be closely controlled and efficiently regulated by means of pH determinations. In this way, many of the difficulties of the paper maker that are due to poorly washed stock, whether bleached or unbleached, may be eliminated. Foaming, loss of sizing, softening of stock, and fading of color are some of the troubles that are well known and much feared by the beaterman, and his usual, though very inadequate, remedy is alum, which is added to neutralize lime or other alkali that may be present. In mills where high-grade papers are manufactured subject to strict specifications for water resistance, it might be advantageous to use pulp storage chests for intermittent neutralizing of the alkaline stock before it reaches the beater. An automatic device for the continuous addition of this neutralizing acid electrolyte would suggest itself where slushed stock is used.

115. Engine Sizing.—The importance of hydrogen-ion control in engine sizing is now generally realized by the paper industry. It has long been known that the stock as it goes to the machine, and the white water as it leaves the wire, should be acid, in order to get perfect operation, but no definite data regarding this acidity were available. The ratios of alum to size varied from mill to mill, some using as much alum as 5 times the weight of the size, while others obtained satisfactory results with equal amounts of size and alum. Naturally, hardness of the water,

composition of the size, conditions of the stock, and use of white water must all be considered; but it is unreasonable to assume that these factors should vary the alum consumption 500%. By aid of hydrogen-ion measurements, it has been definitely established that, in the majority of these cases, almost unbelievable amounts of alum had been wasted, and that by judicious adjustment of the pH value of the stock and the white water, and better washing of the stock before reaching the beaters, considerable savings could be effected The optimum pH for sizing will, to a greater or less extent, always depend on local conditions. The optimum pH for precipitation of aluminum ions in pure solutions is about 5.0 to 5.5; however, this does not necessarily mean optimum sizing results. In some mills, the stock is adjusted to pH 4.5; others are getting satisfactory waterproofing with a pH of 5.8 to 6.0 in the beater; while some have as low as 3.5. No definite rules concerning this practice can be laid down, but local conditions and the grades of paper being made will determine the degree of acidity to be maintained. If the fresh-water supply be abundant and uniform, and the hardness of the water be not subject to seasonal changes, H-ion measurements of the stock in the beater will permit the working out of an optimum for sizing. But where the water supply is small and the hardness of the water varying, beater control may easily end in failure, because of the large amounts of usually alkaline water added on the machine. In these cases, pH determination of white water leaving the wire is the logical way to control acidity.

It has sometimes been found desirable to neutralize a beater with alum before adding size or color. The amount of alum required for this purpose will also depend on local conditions; but from $\frac{3}{4}$ to 1 pound of alum for each 0.1 pH value should be sufficient for a 1000-pound beater at 3.5% consistency.

The pH values of free-rosin size emulsions have also been investigated, and have been found to be pH 8.3 with 6 grams of size per liter, and 7.6 with 0.3 grams per liter. The hydrolysis is considerably retarded by the mass action of the free rosin. The alkalinity obtained by the use of rosin soap in the beater varies from 0.001% to 0.0001% NaOH.

116. Glue Sizing.—In cases where glue is used as engine sizing, pH control will also improve operation. It is known that the isoelectric point of glue, that is, the acidity at which it has

minimum properties, such as solubility, absorption, swelling power, etc., is at a pH of about 4.7: maximum retention of glue by the fiber will occur at this point. Since the amount of glue necessary for obtaining a definite amount of sizing depends on its retention by the fiber, the importance of accurate control of acidity is readily seen. It was found, in work done by the U. S. Bureau of Standards, that foam was at a minimum with the pH of the beater at 4.7.

It is also highly important that the pH of the machine water be checked frequently. Unless the pH of the added water be controlled, this added water may change the pH value of the machine water very greatly, and result in unsatisfactory sizing.

117. Pitch Troubles.—It is well known that difficulty is often experienced because of pitch sticking to the wire, press rolls, and felts, especially in the summer. Campbell[1] studied this problem and found that unless the water used contained sufficient lime or other alkali to give a floc with alum, the pitch accumulated in the white water system in the same manner as though no alum had been added. His conclusion was "that the acidity of the stock was an important factor in causing the formation of pitch on the press rolls." This means that the pH must be accurately controlled in order to prevent this difficulty.

118. Loading.—The pH value is an important factor in loading. Roschier[2] showed that fillers are retained, partly mechanically, and partly as the result of the precipitation of rosin and aluminum hydrate. The pH has a great influence on the retention of fillers. The retention decreases rapidly from pH 4.0 to 5.6, but remains constant between 5.6 and 7.0.

119. Paper Coloring.—In coloring, the important thing to remember is that there is hardly one aniline dyestuff made that will give the same shade if the hydrogen-ion concentration of the stock varies more than about 0.3 pH unit on either the acid or the alkaline side, which makes it difficult to match shades. Around the neutral point of pH 7.0, the shades will change with even smaller variations. A certain excess of alum is required to fix the color on or within the fiber; but this excess is very small, and is normally supplied in the process of engine sizing,

[1] *Pulp and Paper Magazine of Canada*, International Number, p. 118, Jan., 1927: *Paper Trade Journal*, p. 41, Apr. 14, 1927.
[2] *Papierfabr.* 24, Tech. Wiss. Teil, pp. 348, 363, 384 (1925).

except that the following colors require, perhaps, a larger excess: croceine scarlet, oranges and acid blues, and the acid dyes in general if their deepest shade is desired. Hydrogen-ion control of a number of secondary factors—like fresh and back water, as well as acidity and degree of beating of stock, and machine operation—will also contribute to greater uniformity of the shade produced.

120. Frothing of Stock.—The usual remedy for froth in the beaters, on the screens, and at the slices, is alum. Increased acidity will make the individual froth bubbles *smaller*, because of the change in surface tension; but it also makes it harder to break them up by means of sprays. Application of pH control has thrown much light on this phenomenon. It has been shown that the tendency of a solution to froth is decreased as the acidity decreases, and as aluminum hydrate and basic sulphate are precipitated. Increasing the hydrogen-ion concentration by adding more alum will, therefore, actually increase the formation of froth, although it decreases the size of the individual bubbles. A pure sodium-abietate solution, decomposed by alum, gave practically no froth with an acidity equivalent to pH 4.6–5.8.

At this acidity (pH 4.6 to 5.8), all the abietic acid appears as the aluminum salt. Aluminum abietate is difficultly soluble in water, and there are no soluble substances present to reduce the surface tension and produce froth (foam). It has been verified experimentally that alum does not alter the surface tension of water. The excess of aluminum at pH 4.6 to 5.8 occurs as the hydrate or basic sulphate, and prevents the substances soluble in the colloidal state from collecting at the surface and yielding froth. When the acidity is still less, the aluminum hydrate tends to go into solution, the peptizing power of the alkali begins to exert itself, and the froth increases. At the same time, the bubbles become smaller in size and are destroyed with greater difficulty.

In conclusion, it may be stated that pH control is not a panacea for all the troubles of the paper maker. But intelligent application of this method will decrease to a remarkable extent, some of the difficulties that arise.

LOADING AND ENGINE SIZING

EXAMINATION QUESTIONS

(1) (*a*) Name five substances commonly used as loading for paper. (*b*) State which are natural products and which are manufactured products.

(2) What are the usual impurities in clay, and why are they objectionable?

(3) (*a*) Explain the purpose of adding a filler to paper. (*b*) How much filler is generally used?

(4) (*a*) What is meant by retention? (*b*) What factors increase retention?

(5) How may the fineness of a filler be determined?

(6) How is the amount of iron in a filler estimated?

(7) Mention two important differences between engine sizing and tub sizing of paper.

(8) (*a*) What is rosin, chemically? (*b*) Why is carbon dioxide given off when rosin is saponified with soda ash?

(9) Why is the amount of iron in aluminum sulphate important?

(10) What happens when rosin size is mixed with a solution of aluminum sulphate in the presence of paper pulp?

(11) What effect does the amount of soda ash used to make size have on the amount of alum required in the beater?

(12) What effect does hard water have on rosin size?

(13) (*a*) Why is paper sized? (*b*) How is the degree of sizing affected by subsequent treatment of the paper?

(14) What effect has sizing on: (*a*) color? (*b*) strength? (*c*) finish? and (*d*) hardness of paper?

(15) State the sizing requirements of five kinds of paper.

(16) Explain the difference between total acidity as determined by titration and effective acidity as determined by H-ion measurement.

(17) Name some of the applications of hydrogen-ion concentration in pulp and paper mills, and state what savings may be expected from this method.

(18) What difficulties usually encountered in engine sizing may be overcome by pH control?

SECTION 5

COLORING

INTRODUCTION

AUTHORSHIP: This Section was prepared by the Dyestuff Committee of the Technical Association of the Pulp and Paper Industry—Charles G. Bright, Ross Campbell, C. C. Heritage, Kenneth T. King, Clarke Marion, and Carl Schneider, in collaboration with Dr. Otto Kress.

1. Scope and Purpose of this Section.—The pleasing appearance required of the finished paper depends very largely upon the proper manipulation of the coloring processes. The importance of this branch of paper manufacture is realized when it is considered that fully 98 per cent of the tonnage of paper produced is colored in some form, ranging from the tinting of all types of white paper to the production of heavy shades in the standard grades and specialties. Past experience has proved that efficient progress in methods of application has been aided by the cooperation of paper and dyestuffs manufacturers, and the necessity for such cooperation will be made apparent in the following pages. It is the purpose of this Section to place before the reader such information on dyestuffs and their application to paper as is essential to the production of the proper shades and colors. At the same time, a foundation will be laid for the subsequent work that will ultimately be done in connection with the general advancement in manufacturing operations.

While a knowledge of chemistry and physics is of great advantage in studying the application of dyestuffs to paper, it is not as important as a thorough practical knowledge of the working qualities of the individual dyestuffs and of the stocks on which they are used; consequently, no further knowledge of chemistry will be required than is contained in the Section on *Elements of Chemistry*, Vol. II, which the reader is assumed to possess.

Superintendents, beater engineers, and students of paper manufacture should be familiar with the properties of the various

groups of dyestuffs, the variety of dyestuffs in each group, and the action of individual dyestuffs during the process of coloring. A practical working knowledge of the equipment used, and of the different methods of application as applied to various types of equipment, should be acquired. The foregoing, together with a short history of the dyestuff industry, will form a nucleus for a thorough understanding of this subject, which should be supplemented by practical experience in the mill.

2. History of Coloring of Paper.—The coloring of different substances has engaged the attention of man from the earliest ages. Records of the coloring of fabrics go back as far as the year 2000 B. C. With the beginning of manufacture of hand-made papers, it is recorded that vegetable stains and minerals were used for coloring purposes.

Until the latter part of the nineteenth century, paper was colored with pigments, vegetable colors, and lakes (insoluble compounds made from vegetable colors); but, due to the comparatively few pigment and vegetable colors produced, the variety, quality, and uniformity of shades thus obtained were in no way comparable to those made possible by the discovery of the aniline dyestuffs.

3. Mauve, the first aniline dyestuff, was discovered by Sir William Henry Perkin, in 1856, in an attempt to manufacture synthetic quinine by the oxidation of aniline oil. Although this discovery was quite accidental, it formed the basis for the development of many other aniline dyestuffs, and for the subsequent adoption of them by the textile industries. While the manufacture of aniline dyestuffs thus dates back to 1856, their use in the paper industry was negligible until about the year 1890, when their cost of manufacture had been reduced to a point that permitted their use in the manufacture of paper. Between 1890 and 1914, there was a wonderful development in the European dyestuff industry, not only in the variety of products applicable to paper but also in the reduction to very low levels of the cost to the consumer.

4. While the first aniline dyestuff was discovered by an Englishman, keen interest was exhibited by both France and Germany during the early stages of the development of the dyestuff industry. As time went on, Germany began to realize the

importance of such an industry, and she gradually drew ahead of her English and French rivals, due more to the active support of the German Government, which subsidized the young industry, than to any superiority of the German chemist over his contemporaries in other countries. While the business was still in its infancy, the German Government recognized clearly the advantage of building up an industry that would yield good profits in peace times, and which could readily be converted into an organization for the manufacture of munitions of war. That the Germans were correct in their successful efforts to secure a strangle hold on the dyestuff and organic chemicals industries was amply proved by the events subsequent to 1914. Prior to 1879, the Germans had absolute control of the dyestuff industry in the United States. Although from that time to 1914, there were a few companies in this country manufacturing dyestuffs, they were made principally from German intermediates. Through the indulgence of the Germans, the American companies were allowed to continue operations, but only to an extent by which the Germans might benefit through considerations and regulations of the tariff. Several efforts were made by domestic companies to become established on this continent, but they could not compete, on a scale of appreciable magnitude, with the subsidized companies of Central Europe.

The recent World War, with its resulting shortage of dyestuffs, proved the necessity for the establishment of a domestic dye industry. Those concerns which were making small quantities of a few dyestuffs rapidly expanded, in the effort to meet the abnormal demands caused by the stoppage of the European supply. Many new companies were formed, with the result that, today, the American dyestuff manufacturers are able to meet the demands of the paper industry.

5. Source of Aniline Dyestuffs.—**Aniline dyestuffs** are derivatives of certain products obtained from the distillation of coal tar. By subjecting these crude products or **crudes,** as they are termed in the trade, to certain chemical processes, **intermediates** are obtained. On further treatment, the intermediates may be converted into dyestuffs, explosives, poisonous gases, and drugs or pharmaceutical preparations. A plant which, in normal times, is devoted to the production of dyestuffs can thus be readily converted into one for the manufacture of various chemicals used in warfare; and, at the same time, it can produce the

dyestuffs required by the manufacturers. More important even than plant equipment is the training of a large staff of chemists and chemical engineers, who are fitted by education and experience to carry on any research work connected with the exigencies of warfare that they may face. The bond is close between the dyestuff industry and the organic chemicals industry as a whole. There is no branch of chemical industry where a thorough appreciation of the principles of chemistry is more necessary, or where a greater variation in plant methods and equipment must be employed.

Pigments and many natural organic dyes, which had not been on market for several years, owing to the scarcity of aniline dyestuffs during the years 1914–1918, inclusive, are now available in various forms. At the present time, the paper industry has at its disposal a complete line of the aniline dyestuffs necessary for its use, together with a larger volume of pigments and natural organic dyes than were available before the war.

DYES AND THEIR PROPERTIES

CLASSIFICATION OF COLORING MATERIALS

6. Definitions.—**Dyeing** may be defined as the art of coloring (or changing the color of) any material by bringing it into contact with another material of different color in such a manner that the resulting color will be more or less permanent, not being easily altered when the dyed material is subjected to such influences as heat or light, washing, etc. The material used to change the color of some other material is called a **dye** or **dyestuff.** It is not sufficient merely to bring into intimate contact two materials of different color. For instance, very finely powdered charcoal may be thoroughly mixed with water to form a black solution; into this, a white cotton cloth may be dipped and soaked, thereby turning the cloth black. The cloth will not be dyed, however, because by a thorough washing and rubbing, it can be made to resume its original color. To be truly dyed, the coloring matter (dye, or dyestuff) must adhere or cohere to the fiber, and it must be more or less unaffected by such physical and chemical changes as the material may receive.

If a material has been so colored that its color is changed very little, if at all, by the action of light, heat, washing, etc., the dye used is said to be **fast**, and the resulting color is said to be a **fast color**; if, however, the color changes, usually becoming lighter, or changing shade, it is said to **fade.**

Some dyes will not produce the desired color by direct action on the fiber—they will not *stick*, as it were. In such cases, another agent, called a **mordant**, is used. The mordant adheres to the fiber, the dye adheres to or combines with the mordant, and the dye thus becomes **mordanted**, or **fixed.** A mordant is defined as "a substance which, when applied to the fiber in conjunction with a dyestuff, combines with the latter to produce a useful color."

7. Three General Groups of Dyes.—Coloring matters are divided into three general groups; namely, aniline dyestuffs, pigments, and natural organic dyes. The first two groups will be discussed in detail; but in regard to the third group, all that is necessary to say here is that the natural organic dyes[1] include logwood, the red woods (camwood, barwood, sanderswood, brazilwood, peachwood), madder, cochineal, the yellow woods (weld, old fustic, quercitron bark, flavine, young fustic), and Persian berries. All these natural organic dyes require the use of mordants, or other chemical treatment. According to Reginald Brown, F. C. S., indigo, turmeric, orchil, and catechu are used without mordants.

8. Reasons for Using Aniline Dyes.—Of the three groups of dyes, the first group is used more largely than either of the others in the manufacture of paper. Though certain pigments are used in considerable amounts, aniline dyes predominate for the following reasons: (*a*) They embrace a wider range of shades than pigments or natural organic dyes; also, on account of their great variety, they afford more of an opportunity for choice as regards cost, tinctorial power, brilliancy, and resistance to various influences, such as light, acids, or alkalis. (*b*) Aniline dyestuffs do not decrease the strength of finished paper, as is the case with pigments. (*c*) They are easier to handle in the mill than pigments or natural organic dyes, both with respect to manipulation and to uniformity of results. (*d*) With few exceptions, aniline dyes are the cheapest.

[1] None of these now are used much, if at all, in the paper industry.

ANILINE DYES

9. Classification of Aniline Dyes.—From the standpoint of practical application, aniline (or coal-tar) dyestuffs are not classified according to their chemical constitution, but are grouped in accordance with their general properties. There are five such groups; namely, basic, acid, direct (or substantive) dyestuffs, sulphur colors, and pigments from vat dyes of the anthracene series. Each group has distinctive chemical and physical properties relative to their action on the fiber and in their method of application. In order to identify a color by name, it is necessary to know three things: first, the trade name; second, the shade or the distinguishing letter; third, the manufacturer.

10. Trade Names and Distinguishing Letters.—The **trade name** usually bears a reference to the class, properties, chemical constitution, or color of the dye, such as acid blue, fast red, methylene blue, etc.; but, in many cases, it is simply an arbitrary name, such as auramine or rhodamine, given to it by the discoverer or by the first manufacturer.

No fixed rule applies to the **distinguishing letters** following the name of the dyestuff. However, R usually applies to a red shade, 2R to a still redder shade, G or Y to a yellow shade, B to a blue shade, and X or Conc. to the more concentrated brands. Some form of the name of the manufacturer often prefixes the trade name, in certain cases, this designates their class. For example, the names Du Pont, pontacyl, pontamine, and ponsol, of E. I. DuPont de Nemours & Co., signify basic, acid, direct, and vat dyes, respectively.

11. Basic Dyestuffs.—**Basic dyestuffs** are so called because they have a similarity in their chemical behavior to such inorganic bases as caustic soda ($NaOH$) or ammonium hydrate NH_4OH. They appear on the market in the form of a salt, such as the chloride, acetate, oxalate, or nitrate, in which the molecular formula corresponds to (dye base)-oxalate, (dye base)-chloride, etc. Basic dyestuffs are marketed in this form because the color base itself is insoluble in water and must be treated with an acid, to form soluble salts; just as aniline, which is but slightly soluble, becomes the very soluble chloride on treatment with hydrochloric acid.

Basic dyes are characterized by their extreme brightness and great tinctorial power; but, as a class, they possess poor fastness

to light. All basic dyestuffs can be mixed and dissolved with others of the same class; but they should not be mixed or dissolved with acid or direct colors, as they would be thereby precipitated as color lakes.[1] Not only would the color then be wasted, but the precipitated lake would be apt to produce color spots on the finished paper.

Basic dyestuffs are very sensitive to hard water, bicarbonates of lime or magnesia, or any free alkali. When an alkali of this kind is present, it neutralizes the acid, setting free the insoluble dye base, which will appear in the finished paper as a color spot; 50 parts per million of bicarbonates may give trouble. It is for this reason that the recommendation is here made that acetic acid be added before the dyestuff, if trouble from this source is experienced.

When dissolving basic dyestuffs, they should never be boiled; they are best dissolved at a temperature that does not exceed 200°F. Upon boiling, there is a tendency to hydrolyze the dyestuff salt, thereby forming an insoluble base, which greatly reduces the coloring power of the dyestuff. Certain basic dyestuffs, such as auramine, basic brown, Victoria blue, should never be dissolved at a temperature exceeding 160°F.

12. Acid Dyestuffs.—**Acid dyestuffs** also appear on the market in the form of a salt; they are so named because, in the salt, the dye radical takes the place of the acid constituents and gives a molecular formula such as sodium-(dye acid) or potassium-(dye acid).

As a class, acid dyestuffs have a lower coloring power than basic dyestuffs, but they are much faster to light; and on mixed furnishes, give more even dyeings than basic or direct dyestuffs. Acid dyestuffs have no direct affinity for cellulose fibers; they are merely mordanted, or fixed, to the fiber by the presence of size and alum.

13. Direct, or Substantive, Dyestuffs.—The **direct,** or **substantive dyestuffs** are also salts of color acids, being differentiated from the acid dyestuffs by the fact that they do not require alum or, when used in the textile industry, an acid, to develop their tinctorial power. These dyestuffs are so named because of their affinity for cellulose fibers. As a class, the direct dyestuffs have less tinctorial power than the basic dyestuffs; but, in all cases, they

[1] A lake is an insoluble color compound.

are much faster to light than the basic dyes, and, in some cases, than the acid dyes. Some direct dyestuffs are sensitive to hard water, some of the members of this group being precipitated in the form of insoluble lime or magnesia salts.

Direct colors are best dyed at about 140°F. with the addition of salt (sodium chloride) to exhaust (*i.e.*, absorb or use up) the color more freely. Although this procedure is used in mills making blotting papers, it is very seldom resorted to on sized papers, because of the effect on the sizing of the finished sheet. Because of their property of having a direct affinity for the fiber, even though these dyestuffs are generally used for unsized papers, the backwaters[1] in such cases are not always perfectly clear: but they may be cleared by adding a small amount of alum. However, alum has the property of decidedly deadening the shade of all direct dyestuffs; and it is for this reason that the shade produced with a particular dyestuff will be different on sized and unsized papers.

14. Sulphur Dyestuffs.—The **sulphur dyestuffs** derive their name from the fact that sulphur has a predominate part in their manufacture. They are insoluble in water, but are soluble in alkaline sodium sulphide, in which the dyestuff is reduced. This reduced form adheres to the cellulose fiber, and it is oxidized upon exposure to the air, to form the color desired. The only asset of sulphur dyestuffs is their cheapness; but, with the exception of a very few isolated cases in the manufacture of heavy black shades, the decrease in the initial cost of the dyestuff will not offset the greatly increased cost of manipulation. While important to the textile industries, the use of sulphur dyestuffs in the paper trade is practically negligible at the present time.

15. Vat Colors.—The **vat colors** are pigments[2] that are prepared by special processes from the aniline dyestuffs themselves. These pigments are, for the most part, fast-to-light colors that are used almost exclusively in tinting higher-grade white papers. For example, ponsol colors for paper, indanthrene colors, etc. are a special form of the insoluble textile dyestuff of that name. These colors are unexcelled for fastness to light. On account

[1] The water that drains off from the fibers during formation of the paper on the machine wire.

[2] A **pigment** is a solid which, on being reduced to a powder and mixed with a vehicle, can be used as a paint or a dye. A pigment is insoluble in the vehicle, while a dye is dissolved in it. Most pigments are inorganic compounds. In coloring paper, they are sometimes added in the dry state.

of being so much faster to light than the majority of the stocks, they should never be used in paper that contains less than 50% rag unless certain properties of the finished paper must be obtained; for, as will be shown later, there is no need of using, in a paper, dyestuffs that are more permanent than the stock from which the paper is made. Other types of pigment color made from aniline dyestuffs include heliopont colors, solar blues, etc. In all these cases, the dyestuffs are used as pigments, and they may be thrown into the beater in the dry state or in water suspension.

PIGMENTS

16. Classification of Pigments.—There are no general rules for the nomenclature or classification of the various pigments now in use in the paper industry. Each pigment is a separate and distinct chemical compound; hence, those here mentioned will be treated individually.

17. As a rule, pigments are very low in tinctorial power, and they have the disadvantage of lowering the strength of the paper in which they are used; but they increase the weight of the paper, which is sometimes an advantage. Some pigments have the advantage of very low cost, and some are characterized for special purposes by great permanence in resistance to light and chemicals. Pigments also act as fillers to a certain extent, giving, in certain cases, those special characteristics to the sheet that may be desired in it.

The chief types of pigments used in the paper industry are ochers, siennas, umbers, red or iron oxide, chrome yellow, Prussian blue, ultramarine, sap brown, and lamp black. Pulp colors, and certain pigments used in the coloring of coated papers, will be discussed later.

18. Ochers.—Ochers are natural silicates that contain ferric oxide or hydrated oxide of iron; they range in shade from yellow to brown, depending on the degree of hydration. Ochers are marketed as finely divided powders, the degree of fineness having a direct bearing on the quality of the product. Freedom from grit is an important factor in the use of ochers.

19. Siennas.—Siennas are natural silicates that contain manganese oxide. The range of shade of the various siennas is much the same as is that of the ochers.

20. Umbers.—**Umbers** are complex silicates that contain a high percentage of manganese oxide and ferric hydrate. Umbers are a greenish brown in their natural state; but, on burning, they become a rich, deep brown, which produces a desirable brown shade on paper.

21. Iron Oxides.—**Red oxide, oxide of iron,** or **Venetian red** are pigments that depend on ferric oxide or ferric hydrate for their coloring power; they are used to some extent for the coloring of red sheathing, cheap roofing, and a few paper specialties. The use of this product depends a great deal on its quality; for high-grade papers, it must be very finely divided and free from grit. A great disadvantage to the use of these oxides is the dulling action on slitter and cutter knives, and the weakening of the finished sheet, which is caused by the excessive loading required to obtain shades of average depth.

22. Chrome Yellows.—**Chrome yellows** of various shades, ranging from a bright greenish yellow to an orange, are manufactured by mixing lead acetate with sodium or potassium bichromate. Chrome yellows are usually found on the market in the form of a paste, a generally accepted shade being used under the name of *canary paste.* They can also be made directly in the beater, by mixing lead acetate with the stock and adding sufficient sodium or potassium bichromate to precipitate the lead as chromate. Chrome yellows are comparatively fast to light, but are very sensitive to heat and acids, which makes it difficult to maintain a uniform shade throughout a run, owing to variation of temperature in different beaters.

23. Prussian Blues.—Various **Prussian blues,** both in the soluble and insoluble form, are used for coloring. They are made by the precipitation of ferric sulphate $Fe_2(SO_4)_3.9H_2O$ with potassium ferrocyanide $K_4Fe(CN)_6.3H_2O$. The soluble form of Prussian blue is obtained by boiling the precipitate obtained by the reaction of ferric sulphate and potassium ferrocyanide in an excess of ferrocyanide solution. Prussian blue is an economical color to use, and it possesses very good fastness to light. It has two disadvantages; namely, it is very sensitive to alkali, and it appears greenish under artificial light. Soluble Prussian blue must not be confused with the extensively used aniline dyestuff known as soluble blue or acid blue.

24. Ultramarines.—**Ultramarines** of various shades of blue, from greenish to reddish tone, are used for the tinting of higher grades of white papers. They are soluble silicates of sodium and aluminum, containing some sodium sulphide, made by admixture of sodium carbonate, sodium sulphate, clay, sulphur, silica, and charcoal. After heating to a molten mass and cooling, the mixture is finely ground and washed. Ultramarines have the decided disadvantage of being sensitive to acids and alums. The so-called alum-resisting ultramarines are superior for use in the paper industry. The greater the percentage of sulphur and silica in the ultramarine the redder in tone and the more resistant to alum it becomes.

25. Sap Brown.—**Sap brown,** a brown coloring agent of unknown composition, has a limited use in cheaper grades of paper. It is used more as a dyestuff than as a pigment, due to the finely disintegrated state of its particles in solution. It has the advantage of being fast to light, but it is sensitive to hard water. On account of its non-uniformity, difficulties are experienced in maintaining uniform shades.

26. Paris Black.—**Lamp, carbon,** or **Paris blacks,** produced as soot by the incomplete combustion of various oily organic compounds, are used to some extent for the production of gray or black papers. Lamp black, when used in large amounts, has a tendency to streak the paper; it makes paper rub badly, and it is a decided nuisance in the beater room. Due to its fine state of division and low density, it is apt, through careless handling, to get into the air and settle, in the form of soot, on other material in the beater room; however, this can be avoided by careful handling. The lamp black either can be weighed into a paper bag, and the whole bag thrown into the beater, or it can be made into a paste with hot water. It is difficult to obtain uniform results with lamp black, because the depth of the shade depends on the length of time and manner of beating.

SOURCES AND MANUFACTURE OF ANILINE DYES

27. Source of Coal Tar and Crudes.—Aniline dyestuffs are manufactured from coal tar, which is a by-product of gas and coke making. The percentage of coal tar obtained depends on the method of distillation of the coal. The average production

from one ton of coal is, approximately, 12,000 cubic feet of gas, 1200–1500 pounds of coke, and 120 pounds of coal tar.

28. Crudes.—Coal tar contains several different crudes, the most important of which are benzene, toluene, xylene, phenol, naphthalene, and anthracene, and these are separated from one another by fractional distillation. Each crude forms the starting point from which certain intermediates of importance to the dyestuff manufacturer are made. The residue, or **pitch,** which is left after the crude of highest boiling point has been distilled, is used for paving, roofing, and for other similar purposes. After separating the crudes into groups, each group is further purified by additional distillation or crystallization, and it is then ready to be used in the manufacture of intermediates.

29. Manufacture of Intermediates.—The coal tar intermediates may be divided into three groups; namely, benzene intermediates, naphthalene intermediates, and anthracene intermediates, all of which are derived by subjecting the purified crudes to various chemical operations, such as sulphonation, nitration, reduction, oxidation, fusion, and condensation. The yields and purity of the intermediates formed during these operations are greatly influenced by temperature, pressure, concentration, and other factors. By varying the foregoing operations, and the conditions under which they are conducted, a large range of intermediate compounds is obtainable.

30. Azo Dyes.—The scope of this work will not permit of a detailed account of the different processes entailed in the manufacture of intermediates and dyestuffs; but to exemplify the nature of such operations, the following description of one of the most important types of reaction is given. Most of the direct, a large number of the acid, and a few of the basic dyestuffs are called **azo dyes,** because of the nature of the reaction that takes place in their formation from the crudes into the finished dyestuffs.

31. Diazo Dyes.—When a benzene or naphthalene intermediate containing an amino (NH_2) group is treated with sodium nitrite and hydrochloric acid at a temperature around 5°C., a process known as **diazotization** takes place. The amino group of the intermediate reacts with the nitrous acid in such a way as to form a **diazo** compound (see Section on *Elements of Chemistry*, Vol. II, Art. **243**), which will readily unite with other intermediates, forming a series of dyestuffs, according to the

substances so combined. Since there is an endless number of intermediates that may be diazotized, and since there are just as many more with which the resulting compounds may combine, it can readily be perceived that an enormous number of dyestuffs can be formed by substituting different intermediates. Proceeding a step farther, the intermediate with which the diazo compound combines may possess an amino group that is also capable of being diazotized and combined with a third body. In many dyestuffs, four intermediates are thus linked up; in some cases as many as five are employed.

32. Manufacture of Vat Colors.—While the vast majority of basic, acid, and direct dyestuffs are made from benzene and naphthalene intermediates, the vat colors are made from the anthracene intermediates by certain processes of sulphonation, causticization, fusion, etc. These are the most difficult dyestuffs to manufacture, because very slight variations in manufacturing conditions produce entirely different results. The **vat dyestuffs** are so called because they must be reduced in an alkaline solution before applying to the cellulose fibers. Since they are the fastest to light of all known dyestuffs, and since reduction is not possible during the manufacture of paper, these colors are prepared in a special form for the use of the paper industry by reducing to the leuco-compound (or colorless form) in an alkaline solution with caustic soda and glucose, at high temperature, and re-oxidizing in the air, to form pigments of a very fine degree of subdivision.

STANDARDIZATION OF DYESTUFFS

33. Importance of Standardization.—More important to the consumer of dyestuffs than the details concerning their manufacture is the standardization of the finished product. In order to color the paper uniformly, the beater engineer must decrease the number of variables with which he has to contend. He must be assured that when he has once secured a color formula for a given furnish, every barrel of the dyestuff he receives under a given name or designation shall be absolutely uniform with respect to strength and shade.

34. Methods of Standardization.—In the manufacture of paper, it is a physical impossibility to hold the basis weight

absolutely constant; likewise, in the manufacture of dyestuffs, it is impossible for every run of the crude dyestuff to be of exactly the same strength and shade. For this reason, a standard of strength and shade for each individual dyestuff is adopted by the manufacturer, the strength of this standard being slightly less than the average strength obtainable in the crude product, or *crude charges*, as they are called. All dyestuffs, after being filtered and dried, are ground to a fine state of subdivision, and are compared in strength and shade with the standard adopted by the manufacturer. One charge, for instance, may be slightly redder than the standard, while the next may be slightly greener; different lots are mixed together with varying amounts of the standardizing agent, to produce the finished dyestuff, which is exactly the same in strength and shade as the standard adopted by the manufacturer.

35. Standardizing Agents.—The standardizing agent most used for basic dyestuffs is dextrine, while common salt $NaCl$ or Glauber's salt $Na_2SO_4.10H_2O$ is used for acid and direct dyestuffs. Other standardizing agents used in isolated cases are sugar, sodium phosphate, and soda ash. An erroneous impression prevails among certain consumers that dyestuffs containing any of the chemicals just mentioned are more or less adulterated. However, a little reflection will show that this is the only way by which the absolute uniformity of every product can be controlled by the dyestuff manufacturers, and that the selection of a standardizing agent is so made as not to interfere with any subsequent operations of paper manufacture.

36. Reduced Brands.—The practice of adding a standardizing agent to the dyestuff is sometimes abused by unscrupulous concerns, which make large profits by reducing the strength of the standard brands of the manufacturers; this is one cause for the excessive number of dyestuffs of varying concentrations and shades on the market, and it results in a great deal of confusion to the consumer. These are known as **reduced brands**; and whenever such dyestuffs are placed on the market, a definite comparison of their strength with that of the concentrated brands of standard manufacturers should be given. In certain cases, reduced brands work more efficiently in the mill than the concentrated brands, especially where small quantities must be weighed. An example of this is the case of rhodamine B extra

and rhodamine B, the former being five times the strength of the latter. The latter is more generally used in the paper industry, because of the great strength of the rodamine B extra, which makes the weighing of the concentrated form, in tinting white papers or for shading, practically impossible, within the degree of accuracy that must be maintained. Until the reliability of the source of supply is established, laboratory tests should be made on the product samples submitted and, also, on all supplies of dyestuffs received.

37. Mixtures of Dyestuffs.—Mixtures of dyestuffs are made by all dyestuff manufacturers, and they are sold to the trade under either a given name or under a mixture number. They are made by combining two or more dyestuffs to produce a particular shade, by mixing them, together with a standardizing agent, in a standard mixer. Efficient paper-mill practice has proved that, except in special cases, the use of mixtures should be avoided whenever possible. The principal exception to this rule is in the use of mixtures of methylene blue and methyl violet for the tinting of the cheaper grades of paper, such as newsprint; but, even in this case, the authors of this Section consider it to be the best practice to use the individual dyestuffs, in order to shade back and forth in the mill, because of the variation in stocks during different parts of the year.

38. Theories of Dyeing.—Among the various theories of dyeing that have been advanced are the mechanical theory, the chemical theory, the solid solution theory, and the adsorption theory. A full discussion of this subject is not advisable in this work; but, for information concerning these theories or for further information on the manufacture of intermediates and dyestuffs, the reader is referred to the various books on dyestuff manufacture and on textile dyeing, such as: Erfurt, *The Coloring of Paper;* Mathews, *The Application of Dyestuffs*, and the literature of dyestuff manufacturers.

TESTING OF DYESTUFFS

THE LABORATORY

39. The Work of the Laboratory.—The laboratory work in connection with the testing of dyestuffs should be divided into four general groups: first, a test for strength and shade on all

samples of competing products submitted by manufacturers; second, a laboratory check on material received against standard samples, to determine whether the dyestuff being tested is standard in strength and shade; third, laboratory tests to be made to determine the composition of mixtures of dyestuffs and the chemical identity of individual dyestuffs or mixtures; fourth, the approximate matching of mill shades, as a guide to subsequent matching in the mill.

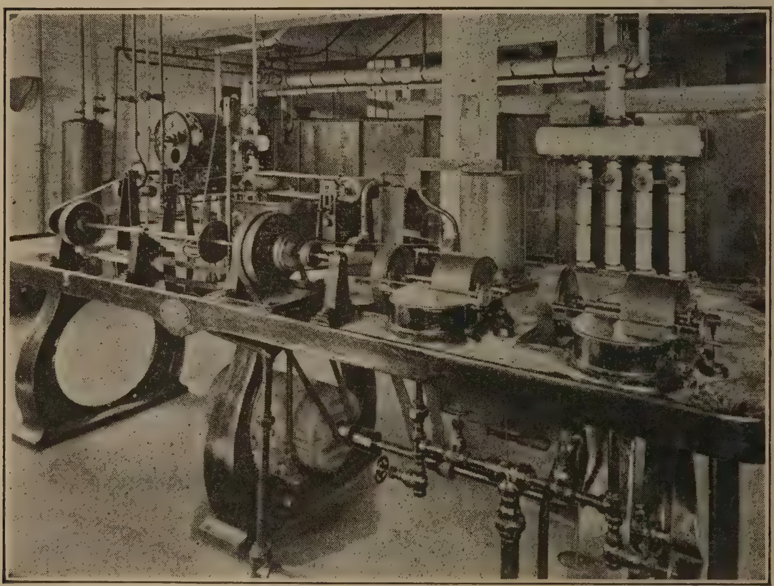

Fig. 1.

Fig. 1 (see "Equipment," Arts. **40**, **41**) shows the operating bench, on which is mounted the equipment necessary for producing a continuous sheet of paper. This consists of a motor, mounted on a frame below the table and driving directly the two small beaters that are shown on the table. From the countershaft at the left of the table, a belt drives the small pump that is used for circulating and agitating the stock in the stock chest, or for delivering the stock into the head box. The stock is delivered from the head box to the vat of the paper machine. A belt also drives the small white-water pump, whose delivery is shown coming over the edge of the head box, and which is controlled by a valve. The paper machine consists of the vat, in which turns a mold covered with wire cloth, and over which travels the felt that picks up the paper deposited on the wire. The felt transfers the paper to the large drying cylinder, shown at the far left, to which the paper sticks and by which it is dried and given a finish. The last belt from the countershaft drives this dryer through a worm gear. The small beaters are driven direct from the motor shaft. By matching shades on a miniature machine of this kind, actual machine conditions, such as return of white water, drying temperatures, etc., are approximated.

40. Laboratory Equipment.—In addition to the general equipment that the ordinary laboratory has, consisting of chemical glass and porcelain ware, burettes, graduated cylinders, pipettes, beakers, volumetric flasks, distilled water, hot plates, etc., the

following equipment is necessary for the special work in connection with the testing of dyestuffs:

(1) Miniature beater of from $\frac{1}{4}$ pound to 5 pounds dry stock capacity, the size depending on the amount of testing to be done. A washer on such a beater is of decided advantage.

(2) A small screen, to be used to thicken the pulp from the beater. This screen can be conveniently and cheaply made by cutting the bottom from an ordinary galvanized-iron pail and

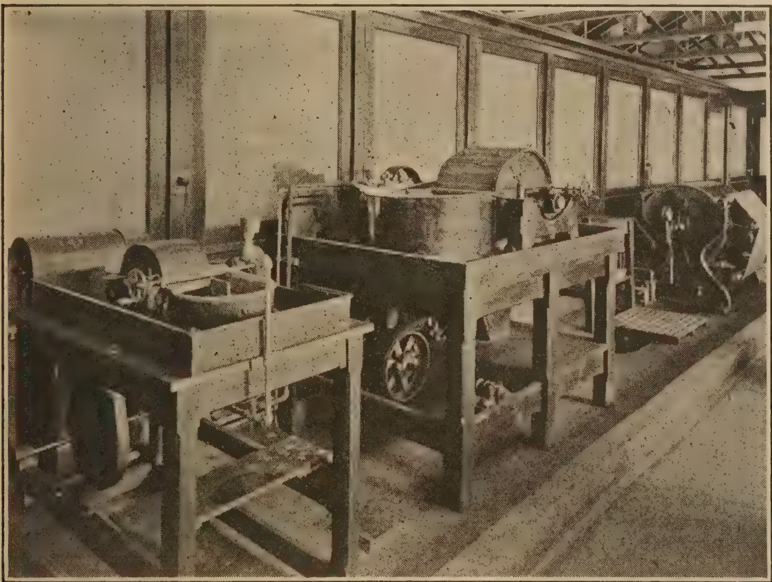

FIG. 2.

Fig. 2 shows two laboratory-size beaters and a cylinder for drying test sheets. The small beater will hold about $\frac{1}{2}$ pound of paper pulp, and the large one about 8 pounds. In either beater, the pressure of the roll on the bed plate can be adjusted by a mechanism similar to that used on the regular mill beaters. Wood pulp or rag stock is placed in the beaters, and in the same proportions as were specified by the mill for the paper whose color is to be matched. The proper percentages of sizing and loading materials are also added, and then a standard solution of the dyestuffs is introduced in successive quantities until exactly the right shade is secured, as indicated by comparison with the test samples. When the proper shade has been obtained, the pulp is made into sheets by means of a sheet machine, and it is then dried on the drying cylinder shown in the illustration. This cylinder is fitted with a felt, and with a steam inlet and a siphon water outlet, like a paper-machine dryer. As shown in the illustration, the steam line carries a pressure gauge. The larger beater is used when a large number of samples are required, or when it is necessary to get a more vigorous beating action than is possible with the smaller beater. These beaters may also be used as supplementary to the equipment shown in Fig. 1. Each machine is driven independently by its own electric motor.

covering it with a piece of paper-machine wire, or by merely fastening a piece of paper-machine wire to a wooden frame.

(3) Five gallon crocks, with covers, for storing moist pulps.

(4) A set of power-driven stirrers, to stir the mixture of pulp, color, size, and alum. In case the amount of work of this type that needs be done is limited, and the cost of installing such a set of power-driven stirrers is not warranted, the writer has found several types of egg beaters on the market that are very suitable for this work.

(5) A suction pulp mold or funnel, made from heavy sheets of copper, in which paper-machine wire is tightly stretched. This

FIG. 3.

Fig. 3 shows two of the work benches in the color laboratory. On the bench in the rear are seen the handles of a receptacle for keeping samples of beaten pulp. Large quantities of pulp can be weighed on the big scales, while small amounts of dyestuffs, or dried sheets of paper, can be weighed very accurately on the delicate balances that are shown farther down the bench. A letter press, used for flattening sheets, can be seen at the end of the bench. On the bench, in the foreground, are the receptacles for the standard pulps required, and the mixing cups for matching shades. It will be noticed that the agitators in these cups are driven by a countershaft, which runs the length of the bench and is driven by a small electric motor. Above the bench are the jars and bottles containing the various dyestuff solutions, and the rosin, alum, starch, clay, and other materials that may be required in making certain papers. It is necessary to approximate, in so far as is possible, all conditions and factors of furnish and manufacture.

wire should be reinforced with a coarser copper-wire screen, supported by a perforated copper plate. The neck of the funnel should be fitted with a rubber stopper, so arranged that it can be mounted either in a suction flask or, preferably, in a large copper receptacle, fitted at the bottom with a stop cock, to allow the back waters to drain away when the box is not in use. An

advantage in using the suction flask is that the color of the back waters can easily be seen, which permits an estimation of the retention of the dyestuff by the paper. Suction may be obtained by the ordinary water-suction pump or by means of a small vacuum pump, connected to a large intermediate vacuum chamber in order to secure a constant suction when the mold is in use.

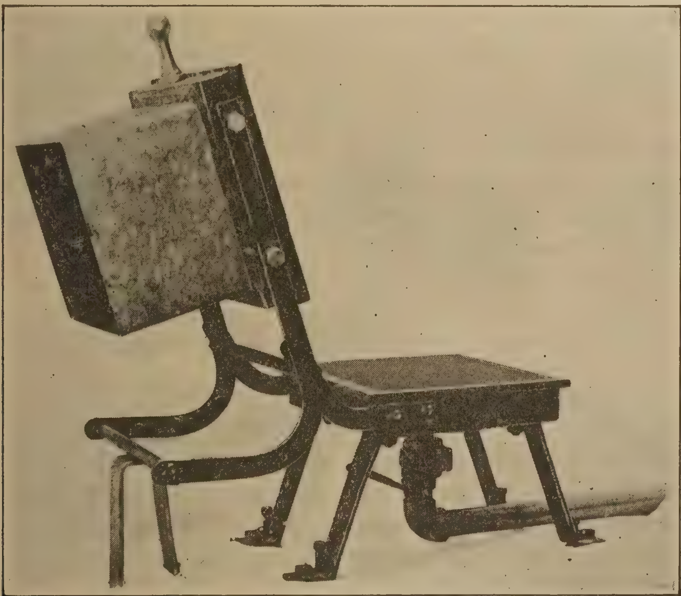

FIG. 4.

Fig. 4 shows a recently developed sheet machine. It consists of a piece of Fourdrinier wire, supported and held flat by a frame on a leg, and so adjustable that it can be made level, and of a box (tipped back in the illustration), which makes a water-tight, machined fit with the frame. A plug valve below the frame (which forms a box) controls the drainage of the water from the stock, which is allowed to become quiescent before being drained.

(6) Several thicknesses of old canvass dryer felt, cut about 16 inches square, to be used with filter paper and blotting paper to couch the sample.

(7) A dryer, with a revolving drum from 1 foot to 4 feet in diameter, made of copper or bronze, either steam or electrically heated, together with a motor for revolving the drum, so the paper sheets are carried in between the surface of the hot drum and the dryer felt.

(8) A supply of one-quart white-enameled cups and of wide-mouth glass bottles.

(9) A rough balance, sensitive to 0.01 gram, for weighing pulps; this balance is in addition to a chemical balance for weighing to 0.0001 gram.

41. Additional Laboratory Equipment.—There is practically no limit to the additional expenditures that can be made for laboratory equipment. There are miniature paper machines on the market, ranging in size from 4 inches to 30 inches trim, which approximate the larger paper machines in the majority of details. Other pieces of experimental equipment used in laboratories for special purposes are available. Among these may be mentioned a tissue-dyeing machine, so arranged that the paper passes through a color box and squeeze rolls, to remove the excess of color; and a miniature two-roll, three-roll, or four-roll calender stack, equipped with water or color boxes, for making experimental runs on calender coloring.

SEPARATION OF DYESTUFFS INTO GROUPS

42. Identification of Coloring Matters.—The identification of various coloring matters requires considerable experience and patience in studying the color reactions by which they are identified. To investigate this question thoroughly, requires years of experience. However, since all large dyestuff manufacturers operate a technical service department in which men who have made this problem a life study are employed to handle this work, the paper manufacturer will obtain more satisfactory results by depending on the dyestuff manufacturer for information on any dyestuffs he wishes to have identified.

Nevertheless, a general knowledge of the separation of dyestuffs into their various groups, and of the tests of behavior toward different chemicals, is important to the paper manufacturer; it enables him to generalize his information, and it assists him in making paper that will meet special requirements.

43. Separation of Aniline Dyestuffs and Pigments.—The first step is to determine whether the coloring matter under consideration is a soluble aniline dyestuff or a pigment. The pigment colors may be easily identified as a class by their insolubility in water, soluble prussian blue being the exception to this rule. The pigment colors used in the paper industry being few

in number, and possessing certain characteristics of appearance, tinctorial power, etc., are comparatively easy to identify.

If the coloring matter is soluble in water, the following procedure should be adopted to determine: first, whether the dyestuff is a single color or a mixture; second, to what group it belongs; third, to determine, if possible, the individuality of the dyestuffs in its particular group.

A small amount of the dyestuff is placed on the point of a knife or spatula, and is gently blown onto a piece of wet pulp or filter paper; this action is called a **blowout.** If the dyestuff is a mixture, the sample is separated into its component parts, each individual particle showing a **spot** of different color.

44. In some cases, where the sample being tested is a mixture of two dyestuffs somewhat similar in shade, it may be difficult to distinguish the component parts from a blowout on wet pulp or filter paper. As a check to the above method, a small amount of the sample is placed on a blade or spatula and blown onto the surface of about 10 c.c. of sulphuric acid, contained in a small porcelain evaporating dish. Different dyestuffs give different color reactions with sulphuric acid, thus indicating at once whether the sample is an individual dyestuff or a mixture.

45. Determination of Mixtures.—Some dyestuffs are mixtures obtained by evaporating to dryness solutions of two coloring matters that have previously been thoroughly mixed. Such a mixture can be determined by making successive dyeings on skeins of plain cotton, tannin-mordanted cotton,[1] or wool, depending upon whether the mixture has been determined to be a basic, acid, or direct dyestuff. If the color is a single dyestuff, the skeins made by a series of dyeings to exhaust the bath, will show a gradual shading down in strength of the same shade. If the dyestuff is a mixture, then the first and last dyeings will differ in shade. Allowance must be made for the variations in strength of the different dyeings, as such variations often cause an apparent variation in shade.

[1] Tannin-mordanted cotton can be prepared by inserting boiled-out cotton yarn into a bath containing 3% tannic acid, based on the weight of the yarn, at 140°F. Raise the temperature of the bath to 200°F., and hold for one hour. Steep until next morning, when the yarn should be wrung out and dried, but not washed. Dissolve 1% to 1½% tartar emetic in water, introduce the dried yarn at 100°F., hold one-half hour, wash, and wring evenly.

46. Separation of Aniline Dyestuffs into Groups.—The second question to determine, if the sample has been shown to be an individual dyestuff, is to what group it belongs. Only basic, acid, and direct dyestuffs, and pigment colors, are used in the paper industry, and tests for those groups only will be necessary. As previously stated, pigment colors can be identified by their insolubility in water, as indicated when a blowout is made on wet filter paper to determine whether the color in question is a mixture.

47. Method of Testing.—Prepare in a test tube a dilute solution of the dyestuff; after adding a few drops of acetic acid, insert a thread of boiled-out degreased wool and one of tannin-mordanted cotton. If the tannin-mordanted cotton is dyed, a basic color is indicated; if the wool is dyed, an acid or direct dye is indicated.

In a second test tube containing a dilute solution of the dyestuff, add a small amount of Glauber's salt; place a cotton thread in the test tube and warm the solution. To determine whether the thread was actually dyed or merely mechanically colored, remove the colored cotton thread and place it in another test tube that contains distilled water, and boil. If the cotton retains its color, the results indicate that the sample being tested is a direct, or substantive, dyestuff.

If the sample under examination colors both the wool and the tannin-mordanted cotton, repeat the dyeing test in a very dilute solution of the dyestuff, to which acetic acid has been added. If the sample is an acid dyestuff, it will color the wool; but, if it is basic, it will stain only the tannin-mordanted cotton. To substantiate the basic character of the dyestuff in the latter case, add some tannic acid to a separate fresh solution of the dyestuff, to which has been added some sodium acetate; if the sample is a basic dye, a precipitate of tannin lake will occur.

48. Subsequent Steps.—The subsequent determination of the individuality of the sample submitted is a process of analytical character that requires a long training. To become efficient in these methods of determination, which are based upon the reactions of the different dyestuffs with weak and strong alkalis, weak and strong acids, reduction, and oxidation, would require more time and labor than the paper manufacturer or the paper-mill chemist could devote to it. As stated before, the dyestuff

manufacturers have men trained to do this work; and, in all cases where the actual identification of the sample is required, the sample should be submitted to the technical laboratories of the dyestuff manufacturers.

OTHER TESTS

49. Testing for Strength and Shade.—The testing of a given dyestuff for strength and shade is more important than its identification, because such tests show the actual money value of the dyestuff to the consumer. All work in the laboratory should be done on the same stock as that to be used on the run of paper for which the particular formula is being worked out. The number of pulps kept on hand in the laboratory depends on the grades of paper made in the particular mill. A laboratory doing work for a mill making numerous grades of paper should carry the following pulps in stock: unbleached sulphite (quick cook), unbleached sulphite (Mitscherlich), bleached sulphite, kraft, soda, groundwood, cotton linters, and rag stock.

50. Preparation of Stocks.—These stocks are prepared for laboratory use by one of two methods. If the stock is to be prepared in the laboratory, it is placed in the miniature beater, where it is beaten until it gives the proper feel or *freeness test* (see Sections on *Refining and Testing of Pulp*, Vol. III, and *Beating and Refining*, Vol. IV). The excess of water is then removed by means of a suction funnel or a laboratory pulp thickener. The pulp is next placed in a crock, and it is kneaded until the moisture present is evenly distributed; the crock must be kept tightly covered at all times. In some cases, it is easier to take the stock directly from the beater room, before the size and alum have been added to the mill beaters; and, after removing the excess of water, the same procedure is followed as with the laboratory-beaten pulp.

51. Moisture Determination.—Moisture determinations should then be made, to ascertain the weight of wet pulp that will be necessary to make a hand sheet of a required air-dry weight. These moisture tests are in constant use, and the moisture content should be accurately determined at frequent intervals. The basis weight for pulp to be used for hand samples varies in different mills, but an average of 2½ grams of air-dry pulp will make a 6-inch diameter hand sheet of average thickness.

The moisture content of the prepared pulps should be of such a consistency that from 10 to 15 grams of the wet pulp will be equivalent to $2\frac{1}{2}$ grams of the dried pulp. Certain pulps, such as jute, manila, kraft, groundwood, and old newsprint, are readily attacked by mold and bacteria. When fermentation or bacterial change occurs, as indicated by the color or odor of the pulp, it is advisable to prepare a new supply.

52. Approximate Methods.—For straight color evaluation work, either unbleached sulphite or mixtures of equal parts of unbleached sulphite, soda, and groundwood are used; which to use depends, of course, on the grades of paper made at that particular mill.

The dyestuff to be tested should be made up into a standard solution, by weighing out on an accurate balance, dissolving in hot water in a casserole, and, after solution is complete, pouring into a volumetric flask and making up to the proper volume. A convenient strength for these solutions is 0.5 gram of dyestuff per liter.

53. For matching a product sample of dyestuff against a standard sample, to determine the strength and shade, the following approximate methods are suggested:

(*a*) Before the solutions are made up to the required volume, spot each of the solutions side by side on a filter paper. Note the difference in strength, and increase the volume of one of the stronger dye solutions (*i.e.*, dilute it) to the point where further tests show the solution to be of equal strength with one of the weaker ones. By comparing the volumes of the two solutions, an approximation to their relative strengths can be made, which will save the time required for determining the actual strength test by making hand samples.

(*b*) Another approximate method, known as the *dip test*, is made by cutting a piece of heavy filter paper in such a manner that it will have two equal legs or forks. The standard solution and that to be tested are then placed side by side, one leg of the filter paper being dipped into each of the two solutions. Upon examining the filter paper after drying, an approximation to the relative strengths can be obtained.

54. Standard Solutions.—In addition to the color solutions, which should be made up fresh as required, the following standard solutions should be kept on hand at all times; namely, size, alum, soda ash, and clay. For laboratory work, a convenient

strength of the solutions of the first three items is $2\frac{1}{2}\%$; the suspension of clay should be approximately 20 parts of water to 1 part of clay, and the bottle containing it should be thoroughly shaken each time before using. The following description gives the methods and relative proportions used very successfully in one laboratory, and they can be used as a guide for other laboratories:

55. On a rough balance, weigh out the samples of wet pulp, equivalent to 2.5 grams air-dry weight, and place in a porcelain-lined cup. Add 50 to 100 c.c. of water, and mix the stock for 5 minutes by means of the mechanical stirrers or paddles mentioned in Art. **40.** At 5-minute intervals, add the color solution, size, and alum; if fillers be used, they should be added at a 5-minute interval before the size. After all material has been added to the cup, and the total stirring time is equal to 39 minutes, add approximately 500 c.c. of water, stirring continuously for a minute or more.

56. Making Hand Samples.—The diluted pulp is now poured into the funnel or mold, and the suction is applied. If a suction flask be used, it is rotated, finally, at an angle that will completely remove the water that tends to adhere to certain portions of the sheet of pulp. The suction is then turned off, and the sheet is carefully loosened on one side by means of a spatula. The sheet is then lifted from the wire and placed between two sheets of filter or white blotting paper. If an ordinary rolling pin be used to couch the sample, the sample sheet and blotting (or filter) papers should be placed between pieces of ordinary dryer canvass. If a wringer is to be used, the amount of blotting or filter paper should be doubled, as the sample, covered by this paper, is passed through the wringer. The remaining moisture should be removed on drying on the rotary drum dryer (Art. **40**) or on a hot-plate. When drying these hand samples on a drum dryer, the sheet should be reversed after every revolution of the drum, to hasten the drying and to avoid the danger of burning the color to the surface.

57. Color Formulas.—All color formulas should be given in terms of 1000 pounds of stock. When the above-mentioned proportions of 2.5 grams of air-dry pulp, a color solution of 0.5 gram per liter, and 2.5% solutions of size and alum are used, every 5 c.c. of color solution is equivalent to 1 pound of dyestuff per 1000 pounds of stock; and 1 c.c. of size or alum is equivalent to 10

pounds of that material per 1000 pounds of stock.[1] When testing individual dyestuffs against a given standard for strength and shade, a 0.2% dyeing is recommended for basic dyestuffs, and a 0.4% dyeing for acid and direct colors; *i.e.* add 10 c.c. and 20 c.c. of dyestuff, respectively, to the pulp.

58. Strength of Yellow Dyestuffs.—For determining the strength of yellow dyestuffs, small standard amounts of either methylene blue or of safranine are added to the stock of both the standard and the product sample dyeings. A greenish tint is produced, which registers more distinctly than yellow on the eye. The strength of the yellow dyestuff is then determined by the degree of shading toward the true shade of either the methylene blue or the safranine.

FASTNESS TESTS

59. Varieties of Fastness.—For every grade of paper, those dyestuffs should be selected which will give the most economical match, consistent with the quality to be maintained. In certain papers, fastness to (resistance to change by) light is the important quality; while in others, fastness to alum, acid, or alkali may be the properties required. Fortunately, the paper industry does not have as many fastness tests to which the dyestuffs must be subjected as will be found in the textile industries. With a few exceptions, fastness to light, acid, alkali, heat, and chlorine are the only tests necessary in the selection of dyestuffs for paper.

60. Fastness to Light.—The first important fact to consider in making a test for fastness to light is that all stocks are discolored in the sunlight with varying degrees of rapidity; and any discoloration that may be due to exposure should be followed through, to determine whether the change in color is due to the pulp, to the dyestuffs, or to, perhaps, a combination of both. Bonds, ledger, cover papers, and wall papers are grades where fastness to light is important. These papers are exposed, in the course of their use, to varying degrees of sunlight, and a dyestuff should be selected whose fastness to light approaches as nearly as is possible to the fastness of the pulps from which the paper is made. In newsprint, wrapping papers, and cheap grades of book

[1] 0.5 g. dyestuff per liter (practically = 1000 g.) = 0.0005 g. per c.c.; 5 c.c. = 0.0025 g.; and 0.0025 g. dye per 2.5 g. pulp = 1 g. to 1000 g., or 1 lb. to 1000 lb. 1 c.c. alum, etc. = 0.025 g. per 2.5 g. pulp = 10 g. per 1000 g., or 10 lb. alum, etc., per 1000 lb. pulp.

and magazine papers, there is never any need to sacrifice cheapness for fastness properties. Consequently, in all papers where groundwood (which discolors rapidly in sunlight and is naturally dull in appearance) is used, basic colors should be adopted, because of their low cost and extreme brilliance.

No paper can be colored with organic dyes so it will be absolutely fast to sunlight. Certain pigments, chief of which are those derived from the vat colors, possess the greatest fastness, while the acid, direct, and basic dyestuffs follow in this order.

61. Tests for Fastness to Light.—There are several ways in which fastness-to-light tests can be made. Exposure to direct sunlight is the most conclusive test, but it is difficult to obtain definite comparative results by this method, because of the varying degree of brightness of sunlight at various times of the day or year. Laboratory tests may also be made means of a fadeometer or an ultra-violet lamp. When comparisons are to be made between two different dyestuffs or between two different stocks using the same dyestuff, the several dyeings should be exposed to the rays of these lamps at the *same* time; because, even in the laboratory, the conditions affecting the heat and strength of the rays emitted by the lamps vary to a certain extent.

For reasons just explained, no numerical values as to the comparative fastness of all dyestuffs is possible. All comparisons must be relative; for which reason, it is recommended that dyestuffs be divided into five general groups, when making such tests, rather than to try to classify them in a numerical order based on percentages.

62. Fastness to Alkali.—Fastness to alkali is important in such papers as soap wrappers, wall papers, and box cover papers, where alkaline pastes are used, or for any type of wrapping papers that are liable to come into contact with alkaline materials. A spot test, with $\frac{1}{2}\%$ solution of caustic soda or 2% solution of soda ash, is sufficient for commercial purposes. Fastness to alkali is also necessary in ledger and bond papers, so they shall be fast to chemical erasures. For testing the fastness against chemical erasure, laboratory samples of the paper, made with the dyestuff material being examined, should be spot-tested.

63. Fastness to Acids.—For dyestuff tests on fastness to acids, colors may be divided into three groups: The first group includes those dyestuffs which are unaffected by alum or a 1% solution of

sulphuric acid; the second group includes those which are affected by alum and sulphuric acid; the third group includes those dyestuffs which are affected by a 1% solution of sulphuric acid, but are not altered by alum.

All direct dyestuffs are affected in shade by the use of alum and by spot tests of sulphuric acid, being dulled to a considerable extent. Acid colors as a class are fast to acids, one important exception being metanil yellow, which is very sensitive to even a slight excess of alum. Basic dyestuffs as a class are not affected by alum; but no general rule applies as to their reactions with sulphuric acid.

64. Fastness to Heat.—No special laboratory tests are possible that will determine the effect of heat on finished paper, for finished paper is never subjected to heat above a temperature harmful to the dyestuff. Nevertheless, the effect of heat on various dyestuffs during the process of paper manufacture is an important consideration, and a practical knowledge of which dyestuffs are thus affected is essential. When the dryers are somewhat too hot, certain acid dyestuffs seem to be drawn to the surface of the paper, giving a decidedly spotty appearance to the sheet and a difference in the color of the two sides (*two-sidedness*). The uniformity of color throughout the run may be seriously affected by variation of temperature of the dryers. Metanil yellow behaves worst in this respect, especially in the presence of a slight excess of alum. Certain basic and direct dyestuffs give a different shade to the paper when it first comes off the machine from that which prevails when the sheet is cooled. When such dyestuffs are used, allowance for this effect must be made when matching.

65. Fastness to Chlorine.—In paper manufacture, trouble with chlorine is experienced where freshly bleached stock is furnished to the beater. In cases where the stock is so poorly washed that large excesses of chlorine still remain, an antichlor, such as sodium sulphite or sodium thiosulphate, should be added to the stock in the beater, to react with the free chlorine. To determine the effect of poorly washed stock upon certain dyestuffs, two hand samples should be run in the laboratory, to one of which should be added a dilute solution of bleaching powder. It should be remembered that the use of antichlor usually leaves the stock acid.

66. Tests Should Be Comparable.—The above-described tests should be made as comparable to the actual working conditions in the mill as is possible. Where time permits, the dyestuff manufacturer will give information as to the reactions of the dyestuff with various chemicals. In other cases, special tests should be made by the above methods, using actual mill stocks and mill solutions, in order to get the best practical results.

67. Effect of Fillers.—All fillers used in the process of paper manufacture have a certain absorptive power for dyestuffs, the degree of absorption depending on the nature of the filler and also on the relative affinity of the dyestuffs for the pulps and fillers. When the fillers are added to the beater in the presence of dyestuffs, a state of equilibrium is established between the amount of dyestuff absorbed by the fillers and that retained by the pulp. Since some of the filler is lost in the backwaters, there is a corresponding loss in available dyestuff. Concrete information concerning relative absorptive powers of various fillers for individual dyestuffs would benefit the paper maker. Research work on this subject has been started, and the results obtained will be submitted to the paper industry as a Report of the Committee on Dyestuffs.

MATCHING TESTS

68. Matching Shades.—Matching shades in the laboratory, together with subsequent work in the mill, is dependent on the character of the stocks, chemical furnish, finish and the class of dyestuff to be used, as well as on the training of the eye to detect readily slight differences in strength and shade. The pulp and chemical furnish is usually given to the laboratory for the sample of paper to be matched. If not, a microscopic analysis will determine the percentage of various pulps in the furnish; and approximate tests for sizing and loading will determine the proportions of size, alum, and fillers necessary. If the paper sample to be matched be heavily calendered, it should be steamed for a few minutes, to graduate the finish to approximately that of the laboratory hand samples, so the true color of the paper sample can be noted. If the sheet be water finished, allowance must be made for the darkening of the sheet by this treatment. In matching samples of glassine paper, satisfactory results can be obtained only when the highly hydrated pulp used in the

manufacture of this type of paper is obtained from the mill beater; for it is impossible to hydrate stock to that degree in a miniature beater. For a given shade, approximately one-half the amount of dyestuff is required for glassine papers that is necessary for the ordinary dry-finished sheets.

69. When matching any new shades, it is advisable to do the work by daylight, a north light being preferable to any other for this purpose. The various daylight lamps on the market are valuable for matching shades when such work cannot be done in the daytime; but the change of shade of different dyestuffs under artificial light will not hold constant under any daylight lamp at present available.

The general method for preparing hand samples from various stocks and with various chemicals has been previously discussed. When matching shades in the laboratory, the same methods apply as when testing for strength and shade of an individual dyestuff, except that a combination of colors is used to match the given sample.

70. Matching Dyestuffs.—To save time in making laboratory matches, the following procedure should be adhered to in order to approximate the quantity of dyestuffs required to obtain a given shade. After the dyestuff, size, and alum have been added to the stock in a porcelain-lined cup, a small amount of the stock should be taken from the cup, squeezed between the thumb and forefinger, and placed on a hot-plate to dry. On comparison with the given sample, an approximation can be made. A small test sample of this kind should be taken out following the addition of each new furnishing of dyestuff; for, in this way, a close approximation can be reached with one weighing of stock, and time is saved in making finished hand samples. When matching a shade where the quantities of each dyestuff are being varied slightly, care should be taken not only to measure out the dyestuff accurately but also to watch carefully the order of the addition of color, size, and alum and the length of time of stirring.

71. Amount of Dyestuff to Use.—By using the methods described in the last article, the quantity of dyestuff necessary per 1000 pounds of stock can easily be calculated. Experience has shown that, as a rule, the amount of dyestuff required to match a sample in the laboratory is usually in excess of that

actually required in the mill. For this reason, it is recommended that, in all cases where a laboratory formula is to be used in the mill, the first addition of dyestuff to the beater should be only 75% of that called for by the laboratory formula.

72. Cost Comparisons.—The determination of the actual color value of a dyestuff is not always a simple problem. This is due to three facts: first, it is very easy to reduce a particular dyestuff 5% or 10%, in order to meet price competition; but this reduction may not be observed by the paper manufacturer, due to variations in pulps or in mill conditions. Second, in certain grades of paper, it is difficult to estimate the depth of a shade within an accuracy of 10%; this is particularly true in the case of yellow shades on all papers, and to all shades on the cheaper grades of wrapping papers and boxboards. Third, while it is comparatively simple to compare two dyestuffs of the same constitution, such as two methyl violets or two methylene blues, it is difficult for the manufacturer to obtain the actual color value when deciding between a low-cost dye of comparatively poor fastness qualities and a higher-price dye of superior qualities. This problem resolves itself into a broad study of what the consumer of the paper actually wants, and to conditions of efficiency in the manipulation of dyestuffs throughout the process of manufacture. It is worth while, however, to make a laboratory comparison of dyestuffs, and, from the percentages required to give matched samples, to calculate, from the price of the dyestuffs, the money value of each in the paper.

PRACTICAL APPLICATION OF DYESTUFFS

COLOR AND BEATER ROOMS

73. Methods of Coloring.—The methods employed in the coloring of paper may be divided into several classes; namely, beater coloring, calender coloring, combination of beater and calender coloring, tub coloring, dipping, specialty coloring by special processes, and coloring of coated papers. Approximately 95% of the coloring of paper is done in the beater; for which reason, the greater part of the remainder of this Section will be devoted to that branch.

74. Color Room Essential.—A well-equipped color room is essential, regardless of the process by which the paper is colored. While slight variations in equipment are necessary in mills doing other than beater coloring, such variations must depend on mill conditions, and they will not be discussed in detail at this point.

Every beater room should have an adjoining color room, to be used for the storage of all kegs and barrels, and for the weighing and dissolving of all dyestuffs. This color room should have a cement floor with two drains; one drain approximately in the center of the room, the other beneath the outlet of a hot-water storage tank. Shelves should be built along one side of the room, for the storage of tins and small containers, and the room should have a wall table, on which the balances are placed.

75. Equipment of Color Room.—A well-equipped color room should contain one rough balance, having a capacity of 20 pounds, weighing to ounces, and a finer balance, having a range from $\frac{1}{32}$ ounce to 2 pounds. The accuracy of these balances should be tested at regular intervals. The authors recommend the ordinary type of computing grocery scale, with a glass top, as best suited to this work.

76. Hot-Water Storage Tank.—A hot-water storage tank, having a capacity of from 50 to 100 gallons, capable of furnishing a constant supply of hot water at a temperature just below boiling, should be available. The best type is equipped with a thermostatic control, which is connected to a steam pipe in such a manner that, when the temperature falls below 200°F., steam will automatically be injected into the tank until the temperature is raised to the desired point, when the steam is shut off.

77. Barrels and Other Containers.—In most cases, the barrels and larger containers are left standing on the floor of the color room. To insure that the dyestuffs are kept dry, it is recommended that a platform be built 2 or 3 inches above the floor, on which to place the barrels. A still better plan is to arrange bins, similar to flour bins, into which the ordinary size barrel will fit; such an arrangement insures a dust-proof storage space in the color room for dyestuffs. If the barrels or kegs of dyestuffs are left open on the floor, the names of the dyestuffs should be stenciled on their sides. It has been the practice of dyestuffs manufacturers to label their containers on the covers. Upon

removing the covers in the color room, they often become misplaced by being set on the wrong barrels. In their powdered form, many aniline dyestuffs have a similar appearance under artificial light; hence, unless the barrels are thoroughly marked on the sides, mistakes are liable to occur that may prove serious.

Copper-lined containers, ranging in capacity from 10 to 25 gallons, are the best for dissolving dyestuffs; but galvanized-iron pails and wooden half-barrels are used extensively for this purpose. Wooden containers, however, have the disadvantage of soaking up a limited amount of the dyestuff when first used, and they are more difficult to clean. Plain iron containers must never be used. Upon emptying the containers, they should be thoroughly cleaned, turned upside down to dry, and thus left in condition for further use.

78. Dissolving Dyestuffs.—The following is the proper method for dissolving dyestuffs: Fill the container with hot water from the storage tank; sprinkle in the dyestuff very slowly with one hand while stirring with the other, the stirring being continued until all the dyestuff is dissolved. After the solution is *complete*, cold water should be added as a safeguard, to prevent the formation of granite fibers on mixed furnishes, which often occurs when the dyestuff solution is added to the beater in a too-hot condition. The quantity of water required depends upon the individual dyestuff. The best general rule to follow is to use a minimum of 40 parts of water to each one part of basic dyestuff. The solubility of some basic dyestuffs is increased by the use of acetic acid, in which case, the best results are obtained by mixing an equal weight of the acid with the basic dyestuff and adding the hot water to the mixture, with constant stirring. Hard water has the property of precipitating all basic dyestuffs and certain direct dyestuffs. Whenever it is necessary to use hard water for dissolving dyestuffs, a small amount of acetic acid should be added to the dissolving water, to compensate for the temporary hardness.

79. Solution Storage Tanks.—In mills where a single grade of paper is run continuously, such as newsprint, it is advantageous to have large mixing and storage tanks for the dyestuff solutions. The best type for this purpose is a cylindrical wooden tank containing a paddle agitator, the size depending on the production of the mill. When storage tanks are used, solutions of basic

dyestuffs should never be made up more than 24 hours in advance; for, after a period of time, the strength of the dyestuff increases. Acid and direct dyestuffs can be stored several days.

80. Beater-Room Equipment.—In addition to that previously mentioned, the equipment necessary for efficient beater coloring includes a small truck, hand mold, hot plate, sieve or strainer, and various volumetric measures, such as pint, quart, and two-quart dippers.

The container that is used for dissolving the dyestuff can be kept on the truck, for conveying the color from the color room to the different beaters. A small hand mold, from 2 to 3 inches in diameter, is used to make hand samples of the stock from the beaters while the initial formula is being built up. If a hot-plate (electric or steam) be used to dry out such samples, the time that would otherwise be lost in running bach and forth to and from the machine room to dry the samples on the paper machine is saved; also, in some cases, such as starting up Monday morning, the dryers may not be hot enough to dry the samples satisfactorily, and further time is lost. The initial small cost of the hot-plate will be more than compensated for by the satisfactory service obtained from it.

DETAILS OF COLORING PROCESS

ACTION OF DYESTUFFS

81. Why Shades Vary.—The shade produced by a dyestuff on different stocks varies between wide limits. With basic colors, stock containing a certain percentage of tannin-like or ligneous material will be colored a much deeper and duller shade than stocks that have been partly or wholly bleached, since the bleaching process removes this material. For example, stocks such as unbleached wood pulps, jute, etc., contain sufficient ligneous material to combine with all the dyestuff, leaving the back waters perfectly clear. Likewise, pulps obtained from different cooks in the same mill will often vary between 25% limits in the amount of dyestuff required to produce a given shade. In other words, a very hard or raw cook requires less dyestuff to produce a given shade than a soft cook does. Although groundwood contains a higher percentage of ligneous material

than unbleached sulphite, the ligneous material in groundwood is not in as actively combinable state as in unbleached sulphite; it is for this reason that a granite effect or hairy fibers are produced in mixed furnishes that contain unbleached sulphite and groundwood.

82. Action of Basic Dyestuffs on Rag Stock.—Rag stock has very little affinity for basic dyestuffs. When using basic dyestuffs on such stock, a certain proportion of the dyestuff combines with the fibers, and a certain additional amount is held on the fibers by the size and alum; but the backwaters can never be cleared up.

83. Action of Acid Dyestuffs.—Since acid dyestuffs have no direct affinity for any type of cellulose fibers, being mordanted to the fibers by the use of size and alum, they can be used on all types of stock with equal success, and will give the most even dyeings on mixed furnishes.

84. Action of Direct Dyestuffs.—As before stated, direct (or substantive) dyestuffs are named from the fact that they have a direct affinity for cellulose fibers. The greater the degree of purity of the fiber the greater is its combining power with direct dyestuffs; for which reason, they color most efficiently the bleached rag and wood pulps. Owing to the fact that the cellulose fiber in groundwood is surrounded by other material, the direct dyestuffs have little affinity for this type of stock; and, in some cases, where the groundwood is coarse, they leave uncolored shives in the paper.

MORDANTS

85. Use of Mordants.—A mordant combines with a dyestuff on or within the fiber, to form an insoluble compound; in other words, it fixes the dye. The paper industry does not use mordants to as great an extent as the textile and other dye-consuming industries, because no material that will interfere with the *sizing* of the sheet may be added in the manufacture of paper. The size and alum act as a mordant for certain dyestuffs, the degree of mordanting depending on the kind of pulp, method of beating, and the properties of the dyestuff. Other mordants are not used to any extent in the paper industry.

86. Coloring Unsized Papers.—Because of the affinity of direct dyestuffs for cellulose fibers, they can be used satisfactorily on unsized paper, such as blotting papers. For heavy shades, however, the addition of 40 or 50 pounds of salt to the beater gives a greater depth of shade and clearer back waters. The action of salt in this case, however, is not that of a mordant—it acts as a "salting out" agent.

In a beater containing cellulose fibers, together with a certain amount of water holding a dyestuff in solution, if a more soluble salt be added to the beater, it will tend to drive a less soluble salt of the same base out of solution. The addition of salt tends to throw the dyestuff out of solution; but, on account of the affinity of the cellulose fibers for this dyestuff, the dyestuff is forced onto the fibers, instead of being crystallized out of the solution. Most dyeings with direct colors are brighter on unsized than on sized papers, because the sodium salt of the dyestuff is much brighter than the aluminum salt that is formed when alum is added to the beaters.

87. Action of Size and Alum.—Acid colors are mordanted to the fibers, in all cases, by the use of size and alum. While the presence of an excess of alum increases the retention of the color on the fibers, better results can be obtained by increasing both size and alum in proper proportions rather than by having an excess of alum only. The fact that heavier sizing increases the shade produced by acid dyestuffs, warrants the assumption that the greater the quantity of size the larger the number of particles there are to which the color may become attached, or by which it may become trapped in the fibers. Pigment colors behave in a manner similar to acid colors in this respect, far better results being obtained on the heavier sized than on the lightly sized papers.

88. Action of Soda Ash, Borax, and Other Chemicals.—When soda ash is used with certain direct dyestuffs, such as the various brands of purpurines and Congo reds, or borax is used with such acid dyestuffs as metanil yellow, it does not act as a mordant; it here serves to neutralize any excess of alum that has been added to size the paper, in cases where alum has a deleterious effect on the shade of the dyestuff.

89. To a limited degree, other chemicals are used as mordants for specific dyestuffs. When certain direct colors are treated

with copper sulphate, their fastness to light is greatly increased; two parts of copper sulphate should be used for every one part of such direct dyestuffs. Lead acetate decidedly improves the brightness and fastness of such phthalic anhydride dyestuffs as eosine, phloxine, and erythrosine.

90. The use of tannic acid, or other tannin-like materials, decidedly mordants basic dyestuffs to the various fibers. The reason their use has not been more completely developed in the paper industry is because iron has the property of darkening tannin; hence, trouble is experienced on account of this darkening action, and the paper is streaked where it comes into contact with iron.

91. After-Treatment with a Mordant.—There is no doubt but that after-treatment of the colored stock with the proper mordant would, in many cases, improve the fastness to light, two-sidedness (see Art. **106**), and would clear up the back waters. A large amount of work is still to be done in connection with this subject before a comprehensive knowledge of proper methods for coloring paper is obtained.

ORDER OF FURNISH

92. Relation of Coloring to Furnish.—The order of furnish was discussed in the Sections on *Beating and Refining* and in *Loading and Engine Sizing* but it is well again to consider it here in connection with the subject of coloring, because it bears an important relation to this subject. It must be borne in mind, however, that the methods employed for coloring paper are necessarily subordinate to those employed to obtain the maximum production of paper of the quality desired, using the equipment at hand. This accounts for the fact that, in many mills, efficient coloring methods are sacrificed for quantity production. A thorough understanding of all the factors affecting production will be of assistance in working out methods that will give the most satisfactory results under existing mill conditions.

93. Opinions Regarding Order of Furnish.—Opinions differ as to the proper order of addition (furnish) of stocks, dyestuffs, size, alum, fillers, etc. to the beater; this is natural, because of the varying water and stock conditions at different mills. In cheaper grades of paper, differences in the quality of the sheet that arise

from failure to follow the best methods of furnishing are less noticeable than in the higher grades, which are subjected to more rigid tests, both as regards their physical properties and their appearance. This matter will here be first discussed on the assumption that the stock furnished is of one type.

94. Stock All of One Type.—With soft water, basic dyestuffs should be added *before* the size and alum. If the water is comparatively hard, the dyestuff should be added *after* the size and alum; or, a small quantity of the alum, sufficient to neutralize the hardness, should be added before the dyestuff, followed by the size and the remainder of the alum.

With acid dyestuffs, the order depends upon the amount of excess alum used in the paper; if only sufficient alum be used to precipitate the size, then no difference will be perceived between adding the dyestuff before or after the size and alum; but, if an excess of alum be used in the beater, better results will be obtained by adding the dyestuff after the size and alum.

Direct dyestuffs should always be added to the beater before the size and alum; because, on account of having a direct affinity for cellulose fibers, the direct dyestuff should be allowed to come into contact with the fiber before it is coated with size and alum.

Where color formulas are built up that contain basic and either acid or direct dyestuffs, the acid or direct dyestuffs should be added to the beater and thoroughly mixed with the stock before the addition of the basic color solution. Where both acid and direct colors are used, they can be dissolved together; but if they are dissolved separately, the solution of direct dyestuffs should be added before that of the acid dyestuffs.

95. A General Rule.—A general rule for the addition of all chemicals, such as copper sulphate, lead acetate, etc., is to add them directly after the dyestuff and before the size and alum; salt should also be added immediately after the dyestuff. But, when soda ash is used, it is an open question as to whether or not it should be added before or after the size and alum. (The authors, personally, do not believe in the use of soda ash, for the good it does is more than offset by its deleterious effects.) When soda ash is added after the size and alum, it tends to dissociate the aluminum resinate, and, at the same time, to replace the aluminum radical in the dyestuff with the sodium radical. Continued beating tends to increase these two reactions, with the

result that the degree of sizing and the comparative brightness in shade will depend upon the length of time of beating.

96. Mixed Furnishes.—When mixed furnishes are used, very careful attention must be paid to the order and method of adding the dyestuffs, to prevent mottling. With basic colors on a mixed furnish of groundwood and unbleached sulphite, the groundwood should always be furnished to the beater first, followed by a cold solution of dyestuff, unbleached sulphite, size, and alum, in the order here given. On mixed furnishes containing wood pulp and rag stock, direct colors, when used, should always be added to the beater in a cold dilute solution. On account of the nature of the fiber, rag stock is always furnished to the beater before the wood pulp; consequently, it is out of the question to consider reversing this order, for the sake of obtaining a more efficient color practice at a decided sacrifice of beater practice. In order to prevent mottling on such mixed furnishes containing rag stock, where direct dyestuffs are used, it is sometimes recommended that these dyestuffs be added to the beater in a dry state as soon as the beater is furnished.

97. Adding Dyestuffs in Dry State.—In many cases, mill practice has designated that the dyestuffs be added to the beater in a dry state; but such practice is bound to result in a slight increase in the dirt content of the paper. Although the dyestuffs of reputable manufacturers are very clean, it is impossible, in the case of any commodity that must be ground and packed, to keep a very small amount of insoluble matter from becoming mixed with the dyestuff. In the cheaper grades of paper, the amount of dirt or dust from the dyestuff will be inappreciable, as compared with the actual dirt in the pulp; but, in the higher grade rag papers, this small amount may be perceptible at times. For the above reasons, the best general mill rule is to dissolve and strain all dyestuffs.

98. An Important Point.—The most important point to remember in connection with the whole subject of order of furnish is that, once a furnish and formula have become established, every beater making that order must be handled in exactly the same manner.

99. Influence of Density.—The density of the stock in the beater, which varies between 2.5% and 8% (depending on the nature of the stock and the type of the beater), has a very

decided effect on the coloring power of certain dyestuffs. As a general rule, the greater the density of the stock in the beater the greater the depth of shade obtained with a given quantity of dyestuff. This is explained by the fact that thorough brushing out of the fibers has a tendency to work the dyestuff into the fibers of all stocks that have a direct affinity for the dyestuff. In the case of acid dyestuffs, the mordanting action of the size and alum on the dyestuff is proportionately increased with the density.

COLOR FORMULAS

100. Building Up Color Formulas.—Every beater engineer has his own individual ideas concerning the best methods for building up color formulas; this is due to the fact that conditions in each mill are different, both in regard to equipment and to furnish. Before deciding upon any definite plan of procedure, the beater engineer must have a real appreciation of the many variables that influence the shade before the pulp comes off the machine as colored paper. The factors that must be taken into consideration are: the consistency (or density) of the stock in the beater, method of beating, type of dyestuff used, the effect of chemicals present, action of colored stock in chests, loss in backwater, color taken up by felts, action of heat of dryers, and finish of the paper.

101. Factors to be Considered.—When the order first goes into the mill to make a certain grade and shade of paper, the superintendent or beater engineer compares the shade with that of samples from previous runs. If a run has been made that closely approximates this shade, he can start coloring his beater with a formula approximately 20% less than the one used on his previous run. Consideration must be given at this point to the matter of amount and shade of broke that may be included in the furnish. On re-pulping broke in the beater, it loses a part of its color strength, the amount lost depending on the class of dyestuff or pigment used in coloring it. Colored broke should be distributed to all the beaters, not all dumped into one. Allowance must be made for the percentage of broke in the furnish and the proportion of coloring strength retained. Precaution should always be taken to see that too much dyestuff be not added at the start; it is far easier to add color to the beater than it is to correct for shade when the strength is too high. The dyestuff, whether in

the form of dry powder or in water solution, should not all be dumped in at one spot in the beater, but should be allowed to flow in gradually during one complete revolution of the stock in the beater, thus giving the color a more even distribution.

102. Use of Laboratory Matches.—In case the beater engineer has no guide to follow from previous runs, he must depend upon his laboratory match to approximate the initial amount of dyestuff he should add to the beater. In case the mill be not equipped with laboratory apparatus for matching shades, a sample should previously have been sent to the laboratory of one of the dyestuff manufacturers, to obtain an approximate formula. It is much better to work from a formula with individual colors in the mill than to have a sample matched by a color house and a mixture of dyestuffs sent to the mill. In the first instance if there is any variation in the stock, water, or chemicals, this difference can be more easily overcome by the use of one or more of the component colors; whereas if the mixture is used, the shade can be varied in depth only. As stated in Art. **71**, all laboratory matches are approximations; they serve their purpose by acting as guides in building up formulas in the mill. These laboratory matches should be cut approximately 25% (Art. **70**), and then built up with one dyestuff or another, in order to obtain the correct shade.

Some color men, however, prefer to get their main shade by using a mixed dyestuff, and to give this any final variation necessary to compensate for the factors mentioned by adding more of one or the other of the component dyestuffs.

103. Matching Shades in the Beater.—After the pulps, color, size and alum have been beaten for a certain length of time, the shade of the stock in the beater should be compared with a small wet portion of the sample to be matched. Also, a hand sample, as previously explained, should be taken from the beater and dried, and compared with the sample to be matched. Only continued practice in the matching of shades in the beater will give the beater engineer a knowledge of just how a shade that has been brought up to a certain point in the beater will work on the paper machine.

That the first few pounds of paper coming over the machine may be of the same shade as that later in the run, it is sometimes necessary to color up the white water, and also to add a small

amount of dyestuff to the fan pump, to compensate for the color built up in the return waters later in the run, and for the color absorbed by the felts. This method should never be relied on unless the beater engineer has had considerable experience in making such additions; a limited experience may cause far more trouble than the good to be derived.

104. Doctoring the Shade.—As soon as the sheet that is representative of the stock in the chests comes over the paper machine, a comparison with the sample to be matched will show whether the shade is correct or whether certain additions will have to be made. There are two methods of making these additions: first, coloring the chest; second, adding an extra amount of dyestuff to the second beater to compensate for the shortage of dyestuff in the first one dropped. Coloring the chest is a difficult process to regulate; it should be avoided whenever possible, because such coloring has a tendency to make the shade run uneven. However, if this procedure be necessary, the amount of stock in the chests is estimated, the requisite amount of dyestuff is dissolved in a very dilute solution, and this solution is slowly added, either in the head box of the Jordan or directly into the chest.

The second method, that of dropping a beater with sufficient dyestuff to compensate for the difference in shade of the first beater, is very satisfactory, provided there is proper agitation in the stuff chests. In any mill making colored papers, it is absolutely necessary to have good agitation in the chests; otherwise, more harm than good is done by trying to regulate the shade by coloring the chest or by dropping the second beater. Further changes should not be made too rapidly after color or additional stock has been added to the chest, because from 15 to 30 minutes is necessary to obtain the true value of these changes over the average paper machine.

The second beater on the floor, before the paper first comes over the machine, should always contain a little less dyestuff than the first beater; for, in case the shade may come a little too heavy, the second beater can be dropped, which will compensate for the increase in shade for the first paper over the machine as compared with the sample submitted. After the shade is once established on the machine, samples of the finished paper should be compared at frequent intervals, particularly, if there be any change with respect to the basis weight or finish of the paper, or

in the amount of suction on either the suction roll or boxes; and the wet stock of each beater on the floor should be matched against the stock in the stuff chests.

105. Taking Samples from the Paper Machine.—Insofar as the writer's information goes, the taking of samples from the paper machine for the purpose of comparing the uniformity of the run in regard to color, has not, up to the present time, been done as well as it might have been. The uniformity of a color run is most effectively observed in the finishing room of the mill, where the whole run is at hand. To imitate this condition in the beater room while making the paper, two methods may be used:

(*a*) A board may be attached to the wall, on which is a row of nails. With this may be used a flat piece of tin, of trapezoidal shape, for cutting out samples of paper, the samples being cut out with this tin as they are taken from the machine. Order number, date, and serial number (as 1, 2, 3, and 4) or reel number may be attached to each sample as it is taken; and the samples are hung up on the board on the wall in the same sequence as they were taken from the machine.

(*b*) A second method, similar to the preceding, is to use a tin plate of rectangular shape, measuring about 3 by 8 inches, for cutting out samples as taken from the machine. As before, the samples are marked with the order number, date, and serial or reel number; but, instead of hanging them on a board, they are kept in a loose-leaf folder.

By either method, the samples may be kept indefinitely; and any irregularities that occur during the run of the paper may be noted on the samples, as well as their cause. This will serve as an explanation, if such be asked for after a long interval, when the details of the run may have been forgotten or recollection may be hazy. The samples are also useful in the finishing room, as they enable the boss finisher to see at a glance whether all rolls can be cut together; or, if a non-uniformity exists, he may select from these samples the rolls that are to be cut together on the cutter.

106. Two-Sidedness.—One of the most important problems in the present day manufacture of paper is the matter of **two-sidedness,** by which is meant difference in shade or texture between the top and bottom of the sheet. The degree of two-sidedness depends on the type of couch roll used, the number of suction boxes, the freeness of the stock, the amount of water

carried and the selection of the dyestuffs. A limited amount of two-sidedness is absolutely unavoidable on machines where a suction couch roll is employed. This trouble is caused by the fact that a certain proportion of the dyestuff used to obtain any shade is merely mechanically fixed, either to the fiber itself or, as in the case of acid dyestuffs, to the size and alum; hence, as the paper is formed on the wire and passed over the suction boxes and suction roll, a certain amount of this mechanically fixed color will be drawn from the bottom side of the sheet. Less trouble in this respect will be experienced with a free stock than with a slow stock.

In considering this problem, it is obvious that the extent to which two-sidedness can be minimized depends on the selection of dyestuffs that will have the greatest degree of adherence to the fibers. The degrees of affinity of different classes of dyestuffs for different stocks has already been discussed. On unbleached pulps, with basic colors, very little trouble is experienced with two-sidedness, because of the direct affinity of the basic dyestuffs themselves for the ligneous material in the unbleached pulps. On bleached wood pulps and rag stocks, direct colors will give a minimum of two-sidedness, because these colors combine directly with the fiber.

107. Combinations of Dyestuffs.—When selecting combinations of dyestuffs for any given shade, those should be selected which have the same degree of affinity for the various stocks that are used in the furnish, in order to prevent different shades of color on the two sides of the sheet. Because of the fact that pigment colors are mechanically fixed within the sheet, the two-sidedness obtained by the use of pigments is far greater than that obtained with the aniline dyestuffs. An exception is in the use of certain pigments made from aniline dyestuffs, which, due to admixture with certain chemicals in their process of manufacture, more or less mordant such colors to the paper fibers; hence, they have less two-sidedness than many of the aniline dyestuffs themselves. By proper methods of sizing, in other words, by the thorough admixture of the size with the stock before the addition of alum (preferably added in a dilute solution), the two-sided effect will be greatly decreased.

108. Effect of Heat.—No general rules apply to the effect of heat on the various groups of dyestuffs. As before stated, in

connection with the dissolving of dyestuffs, Art. **11**, no basic colors should ever be heated to the boiling point. In certain cases, for example, auramine and basic or Bismark browns, a temperature limit of 160°F. for the dissolving water should be adhered to. After the dyestuff has been placed in the beater, no trouble will be experienced from the effect of heat on any color, provided the temperature is not raised above the point that will affect the sizing. On the paper machine, certain dyestuffs have the property of changing in shade, due to the heat of the dryers. The manner in which they change is entirely individual with different dyestuffs. Chrysoidines and basic browns in sized papers have a tendency to be redder when they first come off the machine than they are after the paper has assumed a temperature and moisture content conforming to atmospheric conditions. Certain acid colors have a tendency to burn on the surface of the sheet. In some cases, if the dryers are too hot, this burning will be very spotted, and it will practically spoil the sheet. Dyestuffs that have a tendency to spot should be avoided.

With acid dyestuffs, in many cases, the color itself is very much stronger on the surface than in the middle of the sheet; this is not a disadvantage, except in very heavy papers, such as cover papers. In cases of direct colors, the increase or difference in shade caused by the heat of the dryers is lost as soon as the paper is in equilibrium with atmospheric conditions. For this reason, when matching shades with direct colors, it is a good policy to take a sample taken from the machine and wave it in the air for 4 or 5 minutes, (to cool it) before comparing with the sample to be matched.

109. Effect of Finish.—The degree and type of finish given the paper has a decided effect on the depth of shade obtained with a given quantity of dyestuff. The more highly calendered the sheet the greater will be the depth of shade; in other words, with a given quantity of dyestuff, a supercalendered sheet will have the appearance of being much more heavily dyed than a machine-finished sheet. Water-finished papers have the appearance of greatest depth, as compared with any other type of finish. As stated before, when matching the highly finished sheets, it is necessary to steam them before comparing with unfinished samples coming off the machine. For color comparison, samples should be taken, whenever possible, from the run, before the paper goes through the calenders.

110. Beater-Room Practice.—The general rules that must be followed to obtain efficient beater-room practice vary with different mills, on account of the existing conditions as to equipment and materials. From what has been previously stated, a general idea of efficient operation, as applied to each particular manufacturer, may be obtained. Attention is called to the following points because of their application to any situation:

All vessels in which dyestuffs are dissolved should be thoroughly cleaned as soon as they have been used. Except in certain special cases, dyestuffs should always be dissolved at temperatures just below the boiling point of water, and they should be strained before adding to the beater. During the process of packing, as well as when opening kegs or barrels at the mill, small quantities of dirt and insoluble matter are liable to become mixed with the dyestuff; hence, it is a good general rule always to strain the dyestuff solution. Strainers should be kept scrupulously clean and should be inspected frequently for any damage.

When once a formula has been adopted, it is most essential that the order of addition of different dyestuffs, size, alum, fillers, etc. be strictly adhered to. Samples of all runs, with formulas attached, should be kept by the beater engineer; and, on each sample, all notations regarding speed of machine, basis weight, conditions of stock, etc. should be tabulated, so that in case another run is made that requires changing the formula, an explanation may be obtained as to the cause of such change.

CALENDER AND OTHER METHODS OF COLORING

111. Calender Coloring.—Calender coloring comes next in importance to coloring in the beaters. This process resembles staining rather than actual dyeing; in fact, it is virtually a water finish, in which a color solution is used instead of water only. In calender coloring, the dyestuff solution is allowed to flow constantly into one or more water or color boxes on the calenders, this solution being picked up through the rapidly revolving calender rolls and applied to the surface of the paper as it passes between these rolls.

112. Low Cost.—The principal advantage of calender coloring is its low cost. Acid dyestuffs are most commonly used for

this purpose because of their generally good solubility, and because, having no direct affinity for cellulose fibers, the shade produced runs more uniform than with any other class of dyestuffs. Acid dyestuffs are also more stable to continued temperatures up to the boiling point, which sometimes makes their use advantageous in this type of coloring.

113. Calender Coloring with Basic and Direct Dyestuffs.—Basic dyestuffs are sometimes used in calender coloring in those cases where extreme brightness and minimum cost are more important than uniformity of shade. The basic dyestuffs have a tendency to mottle and streak the finished paper, and to deteriorate in strength upon standing in the hot solution. The direct colors are also used occasionally for calender coloring; but these also have a tendency to streak the paper, and they have neither the advantage of cost nor brightness over the acid dyestuffs.

114. Apparatus Employed.—The apparatus for calender coloring consists of: a tank, or barrel, for dissolving the dyestuff, into which runs the overflow from the water boxes; a solution storage tank, which is set on a platform at a height above the top of the calender stack, from which the pipe to the water boxes is led; a circulating pump, for the purpose of transferring the solution from the dissolving or overflow tank to the storage tank. The strength of the dyestuff solution is determined by the shade required. In cases where the shades are produced by combinations of dyestuffs, concentrated solutions of the individual dyestuffs should be made up and mixed together in the dissolving tank until the proper shade is obtained; they should then be diluted to the proper strength, either in the dissolving tank or in the storage tank. The water boxes are made with one side, two ends and a bottom. The ends are shaped to fit closely the calender roll against which they fit, and leakage is prevented by rubber packing at the ends and a rubber lip on the edge of the bottom. The box is set against the upward turning side of the roll.

115. Formulas for Calender Coloring.—The following procedure is recommended for working out calender-coloring formulas before the actual run is started. A time is selected when the paper going over the machine approximates the furnish of the paper to be colored. The water box is dammed back several

inches from the edge of the sheet, and the color solution, which is being made up in the dissolving tank, is poured onto the face of the calender roll, where the sheet is running dry. This gives the same effect as will be obtained when the color solution is used in the water boxes; consequently, by changing the strength of the solution and the relative proportions of dyestuff in the dissolving tank, the proper formula can be worked out.

As soon as the run is started, the color solution flows from the storage tank into the water boxes, on either or both sides of the sheet, in the same manner as water is applied for the regular water finish. When only one side of the paper is to be colored, water must be run into the water boxes on the opposite side of the sheet, in order to get an even finish and to counteract curling.

116. Efficiency of Calender Coloring.—The degree of efficiency of calender coloring depends largely upon the manipulation of the paper before it reaches the calenders. The degree of sizing also has a decided effect on the results obtained. If the paper is slack sized, the dyestuff solution will penetrate deeply through the surface, giving a greater depth of shade than is the case with a hard-sized sheet; it will also make the paper feel damp, and it will be without snap. With a light or medium-sized paper, only one color box is necessary; but, with a hard-sized sheet, it is sometimes necessary to run two color boxes, in order that the second box may cover up the light spots from the first color box, and thus give a uniform shade. The degree of penetration of the color solution increases with the temperature of the solution and the heat of the calender stack; hence, in order to obtain uniform results, these two factors must be kept constant. A well-formed sheet will also dye more evenly than a wild sheet, because calender coloring accentuates any irregularities in the paper itself. Where trouble is experienced because of streaking on the calenders, the addition of a small amount of soap in the dyestuff solution will usually eliminate this difficulty.

117. Combination Method.—A combination method, whereby the coloring is done partly in the beater and partly on the calender, is often used. The relative proportion of the two methods thus employed depends upon the cost and the results desired. The principal use of calender coloring is on different grades of box boards and container boards, and a great variety of economical shades may be produced on this type of stock.

Through this method of coloring, different shades on opposite sides of the paper or board can be produced by having the water boxes on opposite sides of the calender stack filled with different dyestuff solutions. Just sufficient solution is taken up by the sheet to give it a good finish on the calender stack. Sometimes steam is used in hollow calender rolls.

118. Tub Coloring.—Tub coloring is used to a very limited extent. In this process, the paper, in a semi-dry condition, is passed through a tub, situated approximately half way or two-thirds of the way to the dry end of the machine; and after passing through this bath, and then through squeeze rolls, it is dried. There are no distinct advantages to this type of coloring; it is used only in special cases, where a slight saving in cost over beater coloring can be made, and when greater penetration can be obtained at the same time than by calender coloring.

119. Oatmeal Papers.—Oatmeal papers are used practically exclusively for wall papers, and the oatmeal effect may be obtained by washing a suspension of *wood flour* over the surface of the sheet on the wire. In a majority of cases, the paper itself is highly colored, while the wood flour is in its natural state of color. In some cases, however, the body of the paper is white, while the wood flour is colored in various hues. In some isolated cases, ordinary groundwood is used in place of the flour, but this has never proved satisfactory, on account of being too coarse. Dyestuffs used for this purpose should have the properties of being fairly fast to light, and of resistance to the alkali that is in the paste used for hanging these papers; and must have the property of not bleeding, in order to prevent the wood flour from absorbing the dyestuff in the paper. On account of the requirements just mentioned, direct dyestuffs are generally used for this type of work; but, by careful attention to their method of application, certain acid and basic colors are used very efficiently. Another method is to mix the stock in separate chests and bring them together in a specially prepared head box on the machine.

120. Mottled or Granite Papers.—Granite or mottled papers are made by adding a small percentage of highly colored fibers to the furnish. The amount of these colored fibers ranges from $\frac{1}{4}\%$ to 3%, depending on the intensity of the granite effect desired. The colored fibers are usually made by dyeing either rag or unbleached sulphite with direct colors. The colored

fibers are prepared by coloring a beater of stock, in the regular manner, with direct colors, adding 40 to 50 pounds of salt per 1000 pounds of stock, heating to 140°F., cooling to below 100°F., adding a small amount of size and alum, and then subsequently running the stock into laps on a wet machine. During this last procedure, any color that is only mechanically fixed to the fiber will be washed out; hence, the pulp in the laps will not bleed when it is mixed with the white or natural stock, in the production of the granite papers.

Very good effects in granite papers are obtained by adding to the white stock two or three different shades of pulp that have been colored in this manner. Where the granite fibers are black in color, black stockings are often used. Varied effects can also be obtained by using wool, jute or various long grass fibers in place of rag or unbleached sulphite.

121. Blotting Papers.—The type of color used for blotting papers depends upon the grade or furnish of the paper. In the better grades of blotting paper, manufactured from a large percentage of rag stock and sometimes containing a small amount of soda pulp or unbleached sulphite, direct dyestuffs should be used exclusively. In the very cheap grades of blotting paper containing unbleached sulphite, soda, and groundwood, basic colors are as suitable as direct dyestuffs.

Direct dyestuffs can be more efficiently dyed on the fiber by the addition of 30 to 50 pounds of salt per 1000 pounds of stock, and raising the temperature to 140°F. The addition of a minimum of 10 pounds of soda ash tends to brighten the shade of the direct dyestuffs, and it has no injurious effect on the paper. The objection to the use of soda ash mentioned previously does not apply here, as the paper is not sized. In order more firmly to fix the dyestuff on the fiber, it is the practice of some mills to add a small amount of alum to the beater; but this practice should be discouraged for two reasons: First, any quantity of alum over $\frac{1}{2}\%$ to 1% has the property of destroying the blotting qualities of the paper; second, as stated in Art. **13,** alum deadens the shade of direct dyestuffs, and, in the presence of the heat of the dryers, it often tends to vary the shade sufficiently to make uniform results difficult to obtain. On the cheaper grades of blotting paper containing groundwood, the addition of a small quantity of alum aids materially in the retention and uniformity. Because of the fact that they have no direct affinity for any fibers

and require a mordant, acid colors should never be used for this type of work.

122. Duplex Papers.—Duplex papers can be made at the calenders of a Fourdrinier machine by coloring one side of the calender. In the case of two-ply or multiple-ply sheets made on a cylinder machine, either the top or bottom liner or both can be colored. Duplex sheets can also be made on a Fourdrinier or Harper machine by having a vat and cylinder mold attached to the paper machine, and having the paper from this cylinder mold carried by a felt, so as to meet the paper from the machine wire just after passing through the couch rolls, where the two papers are pressed together into the duplex sheet, as described more fully in Section 1, Part 5, Vol. V.

123. Spray Dyeing.—Spray dyeing is a relatively new process; and it is only within the last few years, that it has developed to considerable commercial importance. Its advantage lies in the fact that very beautifully colored papers can be produced at a low cost, with a minimum consumption of dyestuff.

Spray dyeing may be divided into two types: In the first type, a dyestuff solution is sprayed onto the sheet of paper by means of a spray nozzle, using air under high pressure to force the color solution through fine orifices; and so arranged that it will strike the paper either before or after passing over the first suction box, depending on the effect desired. In the second type, the dyestuff is spattered on the sheet from rotating brushes, which travel through the dye bath and then against a baffle plate, which draws back the hairs of the brushes; and when they pass the baffle and return to their original position, the color is thrown on the sheet. Direct dyestuffs are more suitable for this work.

124. Cloudy Effects.—There are numerous methods for obtaining cloudy effects, either by washing undyed pulp onto a colored stock as it passes over the machine wire or by coloring the pulp and washing it onto a white sheet; in either case, direct dyestuffs should be used. Where the stock used is either unbleached wood pulp or groundwood, basic dyestuffs may be employed for coloring the body of the sheet.

125. Crepe Tissues.—Crepe tissues are colored by the dipping process, which is the same, in many respects, as tub coloring. This coloring is done at the same time as the creping of the paper.

The machine required consists of two steel rolls, the bottom one of which is covered with a closely woven woolen cloth or with rubber, while a doctor blade crepes the paper as it is removed from the upper steel roll, after the paper has passed between the two rolls. The lower roll is always in contact with the dyestuff solution, which is maintained at a constant level in the color box, in which this lower roll revolves. Acid colors are most suitable by far for this type of work, because of their even dyeing qualities; though for very heavy shades, where brightness is more essential than even dyeing qualities, basic colors are used. Direct dyestuffs are employed for this type of work only in rare cases, where certain fastness properties must be maintained.

One essential in the coloring of crepe tissues is to maintain a constant temperature of the dyestuff solution, in order to obtain a uniform depth of shade. In some cases, a small amount of casein is added to the dyestuff solution, as it causes the paper to adhere more securely to the upper steel roll, and gives a better creping effect.

126. Parchment Papers.—In the manufacture of parchmentized paper, the dyed paper is passed through a bath of strong sulphuric acid. Only dyestuffs that will not be affected by sulphuric acid can be used for this type of work. The tests referred to in Art. **63**, will indicate the action of each dyestuff against acids, alkalis, etc., and should be applied when making a selection of dyestuffs for this work. The most secure method is to submit each individual problem of this type of work to the laboratories of the dyestuff manufacturer.

127. Vulcanized Papers.—In the manufacture of vulcanized papers, the dyestuff used must not be affected by the zinc chloride-hydrochloric acid solution employed in vulcanizing. Certain direct dyestuffs are suitable for this work; but, as mentioned in Art. **126**, the safest way is to submit each individual problem to the laboratories of the dyestuff manufacturer.

COLORING

EXAMINATION QUESTIONS

(1) (*a*) Name the principal groups of coloring matters. (*b*) Which group is the most important, and why?

(2) What are the distinguishing characteristics of acid, basic, and direct dyestuffs?

(3) What particular values are possessed by pigments for coloring paper, considered from the standpoint of (*a*) cost? (*b*) permanence? (*c*) tinctorial power?

(4) How is Prussian blue formed? Would it be advisable to use it for coloring soap wrappers?

(5) Mention the principal steps in producing a dyestuff from coal.

(6) (*a*) What is meant by standardizing the strength of a dyestuff? (*b*) How is this necessary operation sometimes abused?

(7) Explain in detail how to determine whether a particular color is a single dyestuff or a mixture.

(8) Describe a method for estimating the coloring power of a dyestuff.

(9) What standard solutions should be kept in the color testing laboratory, and why are they needed?

(10) (*a*) What classes of paper should be fast to light? (*b*) Is change of color always due to the dyestuff?

(11) After making laboratory test and calculation, what precaution is necessary when coloring a beaterfull of half-stuff?

(12) Mention the principal parts of an equipment for a color room in a paper mill.

(13) Explain the dissolving of a dyestuff.

(14) What factors affect the shade of a paper.

(15) Explain the action of size and alum when coloring paper.

(16) (*a*) Explain what you understand by mordanting; (*b*) why is the use of tannic acid for this purpose objectionable?

(17) When the water is hard, what precaution should be taken if a basic dye be used?

(18) How does the density of the stuff in the beater affect the coloring?

(19) (*a*) What is *two sidedness*, and how is it caused? (*b*) how can it be minimized?

(20) Describe the process (*a*) of calender coloring; (*b*) of making mottled papers.

SECTION 6

GENERAL MILL EQUIPMENT

(PART 1)

BY E. F. DOTY AND M. M. KLOSSON

PUMPS AND PUMPING APPARATUS

INTRODUCTORY

1. Importance of Pumps in Pulp and Paper Industry.—The pumping apparatus and the piping systems connected thereto may truly be called the heart and main arteries of the pulp and paper mill; they are vitally important to the operation of the plant. The enormous quantities of water used in the manufacture of pulp and paper necessitates that the water be delivered at every point it is needed in unfailing supply and in the proper manner. Other fluids besides water are thus handled—pulp, stuff, half-stuff, chemicals, etc.—in fact, in every case, except when the fluid flows by gravity to the point where it is used, some form of pumping apparatus and piping system is necessary.

2. Definition and General Classification of Pumps.—For the purpose of this Section, a **pump** will be considered as any apparatus that causes a fluid (liquid or gas) to flow from a lower to a higher level or which causes a fluid to be transported from one fixed point to another fixed point, regardless of any resistance that may be encountered. This definition will therefore include any form of pump (so called) and such other apparatus as injectors, ejectors, pulsometers, etc. While it is possible that every form of pump embraced in the foregoing definition may be used in connection with the manufacture of pulp and paper, only

a very few types are in general use; consequently, only those most commonly employed will be described herein.

Pumps may be conveniently grouped into three general classes:

(*a*) **Hand pumps**; these include suction, lift, and force pumps, and are operated by hand. Their principle of operation was explained in the Section on *Physics*, and they will not be further discussed in this Section.

(*b*) **Power pumps that are direct connected to a prime mover;** most pumps of this class are steam pumps, in which the piston or plunger of the pump cylinder is direct connected to the piston of the steam cylinder. These pumps are commonly called **direct-acting** pumps.

(*c*) **Power pumps**; these include all pumps in which the power that operates them is derived from some source not a part of the pump mechanism. Such pumps may be driven by belts, electric motors, hydraulic motors, etc. Injectors, ejectors, air-lift pumps, etc. may be considered as belonging to this class, or they might be considered as forming another class.

STEAM PUMPS

SINGLE PUMPS

3. Types of Steam Pumps.—Steam pumps may be classified as single, duplex, or of the crank and flywheel type; and either of the first two may be simple, compound, or triple expansion. A **single pump** is one that has one steam cylinder and one water cylinder. A duplex pump is really two single pumps, placed side by side, the steam valve of one being moved by the motion of the piston rod of the other; it might be called a double pump. In either of these two types, as commonly used in pulp and paper mills, the steam follows the piston throughout the entire length of its stroke, i.e., it is not used expansively. In the crank and flywheel type, the admission of steam to the cylinder is cut off before the piston reaches the end of its stroke, and for the remainder of the stroke, the steam is used expansively, thus saving in the amount of steam used. This result is effected by means of the flywheel, which stores up energy up to the point of cut off, and gives it out again during the expansion. Pumps of this type are not met with in the pulp and paper industry.

If the steam cylinder of a single pump is so arranged that the steam is exhausted into another and much larger cylinder immediately behind it, a single piston rod being connected to the pistons of both cylinders, the small cylinder is called the *high-pressure cylinder*, the large cylinder is called the *low-pressure cylinder*, and the entire combination is called a **tandem compound single pump.** If there were three cylinders thus connected to a single piston rod, the first cylinder would be called the high-pressure, the second the *intermediate*, and the third, the low-pressure cylinder, and the entire combination would be called a **triple expansion single pump.** With either of these arrangements of cylinders applied to a duplex pump, it would become a compound duplex or a triple expansion duplex pump. Such pumps, however, are not used in pulp and paper mills.

Pumps in which the steam is used in but one cylinder before being finally discharged are called **simple pumps,** to distinguish them from compound and triple expansion pumps; and since simple single pumps and simple duplex pumps are the only steam pumps used in pulp and paper mills, they will be the only ones discussed in this Section.

4. Description of a Single Double-Acting Pump.—In Fig. 1 is shown a vertical longitudinal section, taken through the center

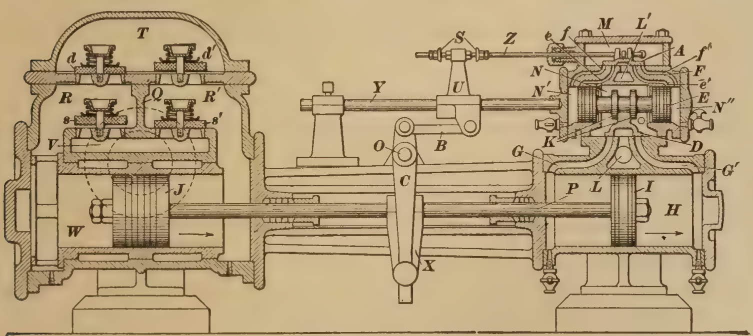

FIG. 1.

line of the cylinders of a direct-acting, single, double-acting steam pump, H being the steam cylinder and W the water cylinder. The steam piston I moves back and forth under the action of steam, which is controlled by the valve D in a manner shortly to be explained. The piston I is attached to one end of the piston rod P, to the other end of which is attached the water

piston J. Consequently, every movement of I is at once communicated to J, which moves in the same direction and through the same distance as I. The total movement of I from one extreme position to the other, which is equal to the length of the cylinder (minus a very short distance at either end, called the **clearance**) is called the **stroke** of the piston, and it is evident that the stroke of both pistons I and J is the same.

Consider the water cylinder first. The cylinder, the spaces R and R', and space T are all filled with water, R being separated from R' by the partition Q. Note that there are four valves—two suction valves s and s', and two delivery (discharge) valves d and d'. These valves are ordinarily held to their seats by springs, as indicated. Suppose the pistons to be moving toward the right, in the direction of the arrows. The water in front of the piston J will then be subjected to the pressure of the steam acting on the left side of piston I; this pressure will be transmitted in all directions (see Section on *Physics*) throughout the space R', forcing valves s' more firmly to its seat and raising valve d' against the resistance of the spring. The water flows through valve opening d' into the chamber T, and forces valve d more firmly to its seat. As piston J continues to advance, a volume of water equal to the volume displaced by the piston in one stroke will be discharged into chamber T, from whence it is discharged into the delivery pipe, which is connected to chamber T, but not shown in the illustration.

When piston J moves to the right, it leaves an empty space behind it, the volume of which is equal to the volume displaced by the piston. The water in chamber R then flows into the cylinder W, behind the piston, thus leaving an empty space above valve s, i.e., it creates a vacuum (or partial vacuum) in the upper part of chamber R. This causes the water to flow through the suction pipe (indicated by the smaller of the two dotted circles) into the space V, raises the valve s, and flows into the chamber R, to fill the vacant space therein. The tension of the springs is slight, only just sufficient to make certain that the valves are properly seated, and to force them to their seats when water is not flowing through the openings.

On the return stroke, valves s and d' are forced to their seats; water is forced through valve d into chamber T and the delivery pipe, and water enters the right-hand end of the cylinder through the suction valve s'.

Referring now to the steam cylinder end, it is impossible (for reasons to be stated later) for the valves, etc. to be in the position shown for the indicated position of the piston. It will be assumed, however, that the valves are in correct position; in which case, steam is flowing through port *G*, is acting on the left-hand side of piston *I*, and is forcing it to the right, as indicated by the arrow. The steam on the right-hand side of the piston (which was used on the previous stroke to force the piston to the left) is exhausting through port *G′*, flows into the hollow part of the valve *D*, from whence it flows out through the exhaust pipe *L*. It is understood that, in order to effect this action of the live and the exhaust steam, the valve *D* has been moved to the right, so that the left-hand outer edge uncovers the opening to port *G*, and the right-hand inner edge uncovers the opening to the port *G′*. On the return stroke, when piston *I* is moving to the left, the valve *D* has been shifted to the left, uncovering port *G′* to admit live steam to the right-hand end of cylinder *H*, and uncovering port *G*, to allow the exhaust steam to flow out through the exhaust pipe *L*.

5. The Steam Valve Mechanism.—It will be noted that there are two steam valves *A* and *D*, and two steam chests *M* and *N*, both of the latter containing steam at full pressure as it comes from the boilers; such steam is called **live steam**, and it is used to do work by imparting movement to the piston *I*. **Exhaust steam,** or **dead steam,** is steam that has done its work. The upper valve *A*, called the *pilot valve*, in the upper steam chest *M* is operated by the piston rod in the following manner:

Attached to the piston rod *P* (by clamping) is an arm *X*; this extends downward, and at the lower end is a pin joint that engages the end of the long arm of a straight lever *C*, which is pivoted on the pump frame at *O*, a fixed pin. To the short arm of the lever *C* is joined a link *B*, the other end of which is pin jointed to the sliding arm *U*, which slides back and forth for a short distance along the fixed rod *Y*. The other end of arm *U* forces the rod *Z* to move with it by reason of the adjustable nuts *S*; and since the pilot valve *A* is attached to the other end of this rod, this valve is also moved. If the nuts *S* were tight against the shoulders of the arm *U*, and if the long arm of lever *C* were, say, 5 times as long as the short arm, the distance moved by valve *A* would be, practically speaking, one-fifth the distance moved by either of the pistons *I* or *J*, i.e., $\frac{1}{5}$th of the stroke. But, if for any reason,

it be desired to shorten the movement of valve A, this may be done by moving the nuts S slightly, so the arm U will be compelled to travel a short distance before touching one of the nuts and moving the valve. Note that valve A moves in a direction opposite to that of the piston I.

Assuming that the piston I is moving to the right, as indicated by the arrow, then, had the positions of the valves been shown correctly, the pilot valve A will have been shifted to the left; this uncovers the steam port f', and admits steam to the closed space N'', the pressure of which forces the piston E (called a *floating piston*) to the left. This same movement of the pilot valve uncovers the port e, and allows the steam that is confined in space N' to escape underneath the valve to exhaust port L'. As will be seen, not all of this steam is thus allowed to exhaust, the remainder being trapped in space N' after the floating piston E has closed exhaust port e; this trapped steam acts as a cushion, and brings the floating piston to rest without jar or shock. The floating piston carries two flanges K, between which fits tightly the top of the main valve D; hence, when E moves to the left, it carries valve D with it. This uncovers the opening to port G', admitting live steam to the right-hand end of cylinder H; but lever C and the nuts S are so adjusted that this does not occur until piston I has reached the end of its stroke. The opening to port G is uncovered at the same time, and the dead steam on the left of the piston is allowed to escape under valve D and through the exhaust pipe L.

When the pump is assembled, the pilot valve is always set so the steam port at one end is open between the upper steam chest M and the corresponding end of the floating piston E. When it is desired to start the pump, the starting valve in the live steam pipe is opened; this admits steam to the steam chests M and N and to one of the spaces N' or N'', causes the floating piston to move, and uncovers the proper port G or G', thus starting the pump by moving piston I. This type of valve makes it possible for the pump to start from any position of the pistons I and J; in other words, there is no dead center. All successful single steam pumps are designed with this end in view.

6. Other Steam Valve Mechanisms.—There are as many kinds of steam valve mechanisms as there are makes of pumps, and most of them have only one valve, i.e., they have no pilot valve. There are some that have no valve gear outside the

pump, with the exception of a hand lever attached to a central valve stem. This type will work very satisfactorily when the pump is operating at fairly high speed; but when it is necessary to reduce the speed, for conditions such as boiler feeding, it will be found that the pump is then inclined to get on dead center and stop running, unless the hand lever is given an occasional shove by the operator. It is beyond the limits of this work to treat this subject further. If the student thoroughly understands the principle of operation of one representative type of single pump, he should have no difficulty in understanding any other type or special case.

The pump just described is called **double acting,** because it pumps water out of the cylinder at either end; every stroke is a working stroke. It is called a **reciprocating pump** because the pistons move back and forth in a straight line.

7. Air Chambers.—Practically all direct-acting steam pumps are, or should be, equipped with an air chamber on the delivery pipe. This is usually a pear-shaped arrangement (see Fig. 6), the volume of which is about $2\frac{1}{2}$ to 3 times that of the pump displacement, and it is placed as close as possible to the pump.

The purpose of the air chamber is to prevent shocks and to make a more uniform flow in the delivery pipe. As the water leaves the pump, it enters the delivery pipe and air chamber, compressing the air therein to an amount corresponding to the pressure moving the water. At the end of the stroke, when the pump reverses, the compressed air in the air chamber expands, causing the water in the delivery pipe to continue to flow. Without the air chamber, or its equivalent, the water in the delivery pipe would come practically to rest at the end of each stroke; this would make the discharge valves close very suddenly, and the column of water falling back would cause severe shocks. It would also take considerable power to put this water in motion again. The air chamber is very similar in its action to the action of a flywheel; it stores up energy, which is given out again later.

Air chambers are frequently placed on the suction pipe also; they may be similar in shape to those on the delivery pipes, or they may be an extension of the suction, closed at the upper end. Such air chambers are frequently called *vacuum chambers,* because the pressure of the air in them is always less than the pressure of the atmosphere. When water is flowing into the pump, the air in the vacuum chamber expands and helps to force water through

the suction valve, and the pressure of the atmosphere forces water through the suction pipe to balance the reduced pressure in the vacuum chamber. The air in the vacuum chamber is compressed somewhat during the discharge; and the vacuum chamber thus acts as a reservoir, which receives from the suction pipe a nearly steady supply of water, but which is delivered intermittently to the pump. The vacuum chamber makes the pump work more smoothly, and it prevents water hammer and pounding.

8. Pump Pistons.—A section through a pump piston is shown in Fig. 2. The box C and plate E form the piston, which is kept from sliding on the rod R by a shoulder at G, and is prevented

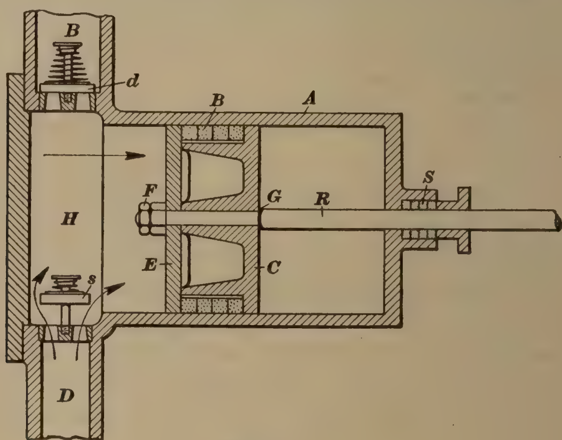

FIG. 2.

from getting off the rod by the double nuts F. The packing rings B, of square cross section, are made of rubber or some other yielding material; their purpose is to keep the water from leaking past the piston when it is under pressure and is being discharged. The cylinder A here shown is for a single-acting pump. When the piston is moving in the direction of the arrow, it leaves a vacuum behind it, and water rushes into the space H through the suction pipe D, forcing open the suction valve s. The pressure of the water in the discharge pipe B keeps delivery valve d to its seat. On the return stroke, the pressure exerted by the piston on the water forces valve s to its seat, raises valve d, and discharges the water drawn in during the preceding stroke up the pipe B. The purpose of the stuffing box S is to make a tight fit

for the piston rod; it is not so important in this case as it would be if the pumping were double-acting, since, in that case, without a good stuffing box, water would leak out at that point.

There are, of course, many makes of pistons for the water cylinder, but the principle is the same in all; and they must be packed tight, to prevent leakage.

9. Pump Plungers.—When plungers are used instead of pistons in the water cylinders, they may be *packed*, as it is termed, in several ways. The water cylinder of a single-acting plunger pump is shown diagrammatically in Fig. 3. The plunger P works through a stuffing box S. The plunger is a hollow cylinder of smaller diameter than the water cylinder. As it moves to the

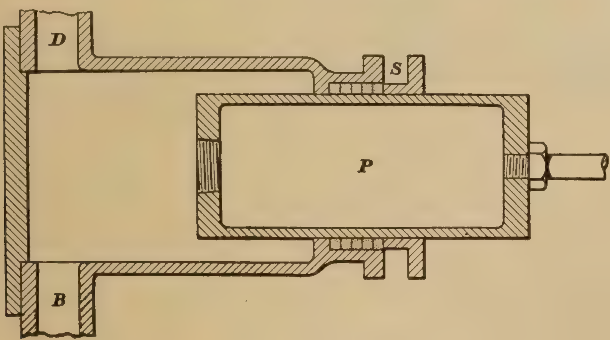

FIG. 3.

right, it leaves a vacuum behind it, and water enters the cylinder through the suction pipe B. On the return stroke, the suction valve is closed, and water is discharged through the delivery pipe D. Such a pump is necessarily of the **outside** (or **end**) **packed** type.

10. A double-acting outside packed pump is shown diagrammatically in Fig. 4. The plungers P and Q are attached to the yokes Y' and Y'', which are, in turn, connected rigidly to each other by the rods T. Plunger Q and yoke Y' are attached to the steam piston rod N. As a consequence of this arrangement, any movement of the steam piston is at once communicated to a like movement of *both* plungers. The cylinder A is divided into two equal parts by the partition F, thus making it virtually two cylinders, one for either plunger, and each has its own suction and discharge valves, not shown in this cut. D' and D'' repre-

sent diagrammatically both the suction and discharge valves of two cylinders, the suction valves being located just beneath the discharge valves, as in Fig. 1. Suppose the plungers are moving toward the left, as indicated by the arrow; this forces water out of chamber C' through delivery pipe D', and it draws water into chamber C'' through suction pipe D''. On the return stroke, water is drawn into C' through suction pipe D' and is forced out of C'' through delivery pipe D''. As will be noted, this arrange-

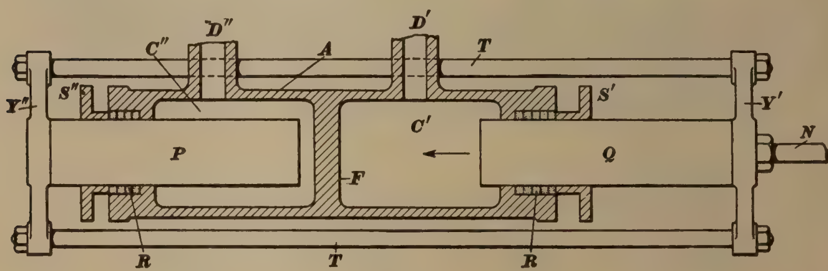

Fig. 4.

ment virtually amounts to connecting two single-acting pumps at their ends; but, by connecting the two pipes D' and D'' to a common delivery pipe, and doing the same thing to the two suction pipes, the final effect is that of a double-acting pump, the water being drawn into one end of the cylinder A and discharged through the other end simultaneously during each stroke. The stuffing boxes S' and S'' being on the outside ends of the pump, this is an outside packed pump.

11. A center packed pump is shown diagrammatically in Fig. 5. Here a single, long plunger P works in two cylinders, joined

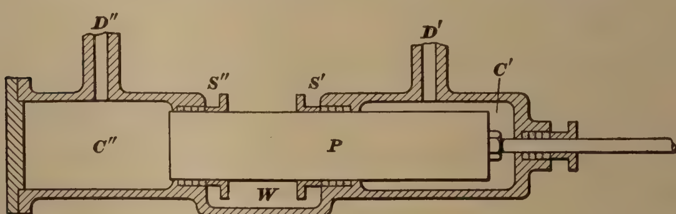

Fig. 5.

at W, and cast in one piece. The stuffing boxes S' and S'' being located in the middle, this is called a center packed pump. Insofar as the action of the pump in relation to its suction and

discharge valves is concerned, this pump is the same as that illustrated in Fig. 4.

12. An **inside packed pump** is shown in Fig. 6, which is a section through the pump cylinder. The partition *F* divides the cylinder into two equal chambers *A* and *B*. The plunger *P* works in a bushing *G*, which can be adjusted to provide for wear. The water enters through the suction pipe *S* and fills the chamber *C*, from whence it passes through suction valves s' and s'' to the

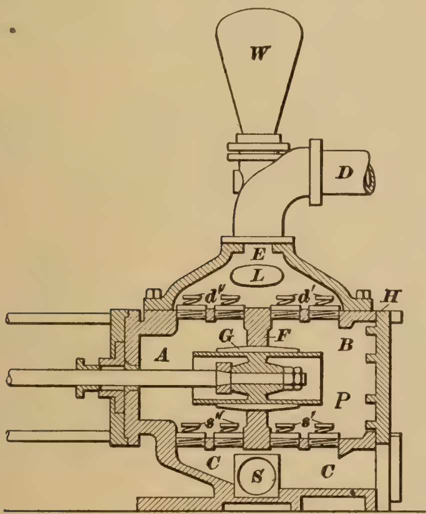

FIG. 6.

pump cylinder. The water is discharged through valves d' and d'' into chamber *E*, and through opening *L* into air chamber *W* and delivery pipe *D*. This is called an inside packed pump because it is necessary to remove the cylinder head *H* in order to inspect the packing of the plunger.

DUPLEX PUMPS

13. Purpose of the Duplex Pump.—A **duplex pump** consists of two single pumps, placed side by side, and so arranged that the motion of the piston (or plunger) rod of one pump operates the steam valve of the other. These pumps are both double acting; and, since they do not both begin and end their strokes at the same time (as will be shown later), there is a steadier flow of water, both in the suction and the discharge pipes, than is the

case with the single pump. At the end of each stroke of the single pump, the moving parts come to rest momentarily, during which period, there is a perceptible decrease in the volume of water discharged. But, with the duplex pump, there is no time during which both pistons are motionless; when one piston is at the end of its stroke, the other piston is at the middle of its stroke, and it is moving at its highest speed. This results in a much steadier rate of discharge, the discharge pressure is maintained much more nearly uniform, and the stresses, strains, and vibrations on the pumping system that are caused by variation in pressure are greatly reduced.

14. Description.—With the exception of the steam-valve gear, the same types of construction are used for both single and duplex pumps; that is, the details of the steam and water cylinders, pistons, plungers, rods, water valves, etc. are all similar in

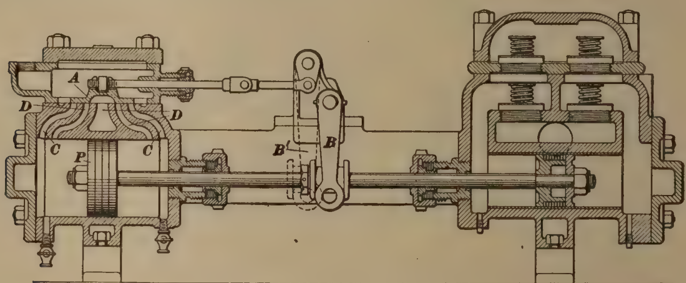

Fig. 7.

design. In those cases in which manufacturers offer both single and duplex types, many of the parts are so standardized that they are interchangeable in pumps of either type.

A longitudinal vertical section through one set of cylinders of a duplex pump is shown in Fig. 7. The usual form of steam-control mechanism consists of two ordinary D slide valves, one for each steam cylinder, though piston valves are used for high-pressure pumps and superheated steam. Both cylinders have their own steam and exhaust ports *C* and *D*, respectively, which are usually in line with each other in both cylinders. Instead of a single port for both steam and exhaust from either end of the steam cylinder, as in Fig. 1, there are two ports, *C* being the steam port and *D* the exhaust port; hence, when the piston is very near the end of its stroke and has closed the exhaust port *D*, the

remaining steam is trapped and compressed, thus assisting in bringing the piston more gradually to rest.

The valves *A* are always so set that when the pump is at rest, a steam port is slightly open to one of the cylinders at one end. When the valve in the steam pipe is opened and live steam enters the cylinder through the slightly opened port, starting the pump, one of the levers *B* or *B'*, which control the movement of the valves *A*, moves the valve in the other cylinder, opening the port and starting up the other piston in a direction opposite to that of the piston that started first. It will thus be perceived that both steam pistons of a duplex pump do not start at the same time, and neither do they stop simultaneously—one piston begins to move, and then the opposite piston starts up. This alternate movement of the pistons of the duplex pump continues throughout its operation, and is inseparable from this type of steam valve control, thus insuring a steadier discharge, as mentioned in Art. **13.** Likewise, at the end of each stroke, there is a perceptible pause, which gives the water valves time to seat without jar or shock. The valve *A* is here shown in its central position, with all four ports closed. Any movement of it to the right will open the steam port *C* on the left and the exhaust port *D* on the right. In actual operation, the valve *A* and piston *P* could not both be in their central positions at the same time, as here shown. The pump illustrated in Fig. 7 is a characteristic design of a duplex pump of the packed water-piston type. These pumps are divided into two classes—low-pressure and high-pressure pumps.

15. Low-Pressure Pumps.—The low-pressure, or so-called tank, pumps are manufactured for a maximum water pressure of 75 to 100 pounds per square inch working pressure; their water cylinders are designed to withstand the stresses and strains due to these maximum pressures, and their steam cylinders are capable of driving the water pistons against these maximum pressures, when they are supplied with steam at 100 pounds per square inch initial pressure.

These pumps, as their name implies, are suitable for general low-pressure service up to their limits of working pressure; they are used for pumping water or other liquids that are comparatively free from gritty or abrasive material that would injure the cylinder walls and cause leakage past the pistons. Pumps of this class are not adapted to ordinary boiler feeding, because the strength of the water cylinders and the ratio of the area of the

steam piston to that of the water piston are not such as to render them suitable for this service.

16. High-Pressure Pumps.—The general service type of packed piston pumps are usually designed for maximum water pressures of 150 to 200 pounds per square inch; the proportions of the steam and water cylinders are such that these pumps are suitable for operating against the maximum water pressures for which they are designed when supplied with steam at a pressure of 100 pounds per square inch. They are adapted to boiler feeding, water works, and general water supply service, where comparatively moderate water pressures prevail.

17. Plunger Pumps.—For heavy work and high water pressures, plunger pumps are preferred to piston pumps. A longitudinal vertical section through a center-packed, duplex plunger pump is shown in Fig. 8; this is essentially the same design as was shown diagrammatically in Fig. 5. A pump of this type is

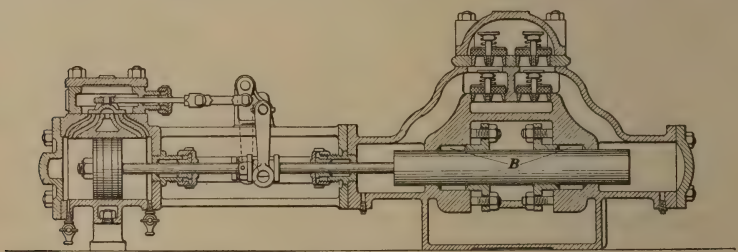

FIG. 8.

adapted to working against water pressures of 150 to 300 pounds per square inch pressure. The combinations of steam and water cylinders available usually cover a range that will enable the pump to work against a water pressure of 200 pounds per square inch when the steam pressure is 100 pounds per square inch, and up to 300 pounds water pressure when the steam pressure is 150 pounds. These pumps are preferred where gritty water or other liquid is to be handled, since any leakage through the packings can be seen without examining the interior of the pump. The packings can easily be adjusted from the outside, and scoring of the plungers caused by grit working into the packings can be observed and rectified before it becomes serious.

18. For still higher water pressures, the standard type of reciprocating pump is the outside-packed plunger type; Fig. 9 is a longitudinal vertical section through a duplex pump of this class.

It will be noted that this corresponds to the water end shown diagrammatically in Fig. 4. This construction is best adapted to very high water pressures, such as extra-high boiler pressures, hydraulic press, and heavy-pressure, hydraulically-operated machines in general. These pumps are seldom used or recommended for water pressures lower than 250 pounds per square inch; not because they are not adapted to lower pressures, but

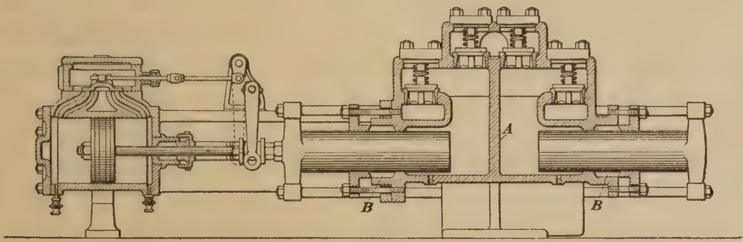

Fig. 9.

because the center-packed plunger or packed piston type is just as suitable for such conditions, and is less expensive. The outside-packed plunger pump is used for water pressures up to the maximum for which pumping machinery may be required.

19. Comparison of Single and Duplex Pumps.—The single pump is not, perhaps, as popular generally as the duplex pump, though there are many engineers who have a strong preference for the single type. Generally speaking, it is more economical in the use of steam than the duplex pump, because the clearance spaces in the steam cylinder may be smaller for a pump of given capacity. Since the steam filling the clearance spaces and ports does no work and passes out with the exhaust, it is a total loss; hence, any reduction in the volume of the clearance spaces results in a direct saving of steam. Again, with the single pump, there is somewhat less possibility of "short stroking;" that is, there is less liability of the pistons not making a full stroke at all speeds. Also, in many cases, the piston speed or number of strokes per minute of a single pump may be increased above that permissible in the case of a duplex pump.

The single pump is built with the same kind of water ends, cylinders, pistons or plungers, and pump valves as are used for the duplex pump. These pumps are built for light, medium, and heavy pressure service. They are in demand for boiler feeding in plants up to 2500 h.p. capacity; for steam-heating vacuum

systems, and whatever moderate vacuum is required; for small water supply, where intermittent duty is required; for hydraulic elevator service and heavy-pressure hydraulic systems. Their principal uses in pulp and paper mills are as boiler feeders, vacuum pumps, and for fire service. Duplex pumps may, of course, be used for these same purposes, especially in the case of fire pumps.

20. Area of Steam and Water Cylinders.—By **area** of a steam or water cylinder is meant the projected area at right angles to the axis of the piston or plunger that works in the cylinder. The steam piston is usually larger in diameter than the water piston or plunger; for this reason, the water piston can work against a higher specific pressure than the specific steam pressure. Let

P = the total pressure on either piston in pounds;
p = pressure on steam piston, in pounds per square inch;
p_1 = pressure against which water piston acts, in pounds per square inch;
d = diameter of steam piston;
d_1 = diameter of water piston or plunger;
a = area of steam piston;
a_1 = area of water piston or plunger;

then, since the total pressure exerted on the steam piston is transmitted undiminished to the water piston,

$$P = pa = p_1a_1,$$

whence,

$$\frac{a}{a_1} = \frac{p_1}{p}.$$

Since areas of circles are proportional to the squares of their diameters,

$$\frac{d^2}{d_1^2} = \frac{p_1}{p}; \qquad (1)$$

or,

$$d = d_1\sqrt{\frac{p_1}{p}}. \qquad (2)$$

Suppose, for instance, the diameter of the water piston is 8 inches, that the water pressure is 250 pounds per square inch, and the steam pressure is 100 pounds per square inch; then the diameter of the steam piston must be, substituting in equation (formula) (2),

$$d = 8\sqrt{\frac{250}{100}} = 8\sqrt{2.5} = 12.65 \text{ inches.}$$

The diameter of the steam piston might be made $12\frac{3}{4}$ inches, or even 13 inches; if the latter, allowance would be made for the steam pressure not quite reaching 100 pounds. Thus, from equation (1),

$$p = \frac{p_1 d_1^2}{d^2} = \frac{250 \times 8^2}{13^2} = 94.7 \text{ lb. per sq. in.}$$

AIR AND VACUUM PUMPS

21. Air Pumps.—Strictly speaking, an **air pump** is one used for pumping air only, or air mixed with vapor or other gas. Such pumps are used for creating a vacuum or partial vacuum, as, for example, in the suction boxes of the paper machine. An air pump for this purpose is shown in Fig. 10. See also *Paper-Making Machines*, Part 1, Vol. V, where the subject is further discussed.

The pump in this case is a power pump, being driven by a belt. The suction-pipe connection is attached at S to the pipe going to the suction boxes, and the delivery pipe is attached at D. The plunger P is about to begin the up stroke and draw air and a mixture of water and fiber into the pump from the suction boxes, through the lower valve. On the return stroke, this valve closes, the upper valve lifts, and the air, etc. discharge through D. This pump, therefore, is a single-acting pump. Strictly speaking, it is a vacuum pump rather than an air pump, and it is commonly called a **suction pump**.

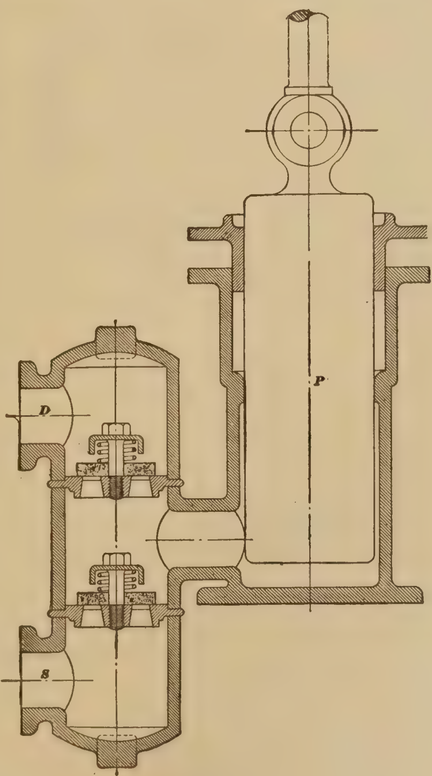

FIG. 10.

22. Air and Vacuum Pump.—Another form of air and vacuum pump, suitable for attachment to a jet condenser, is shown in

Fig. 11. This is also a single-acting pump, and may be driven by a steam engine (as any direct-connected steam pump), belt, electric motor, etc., it may be a single pump or a duplex or triplex pump.

The piston *P*, commonly called the bucket, has a conical bottom, which fits the bottom of the cylinder, also conical.

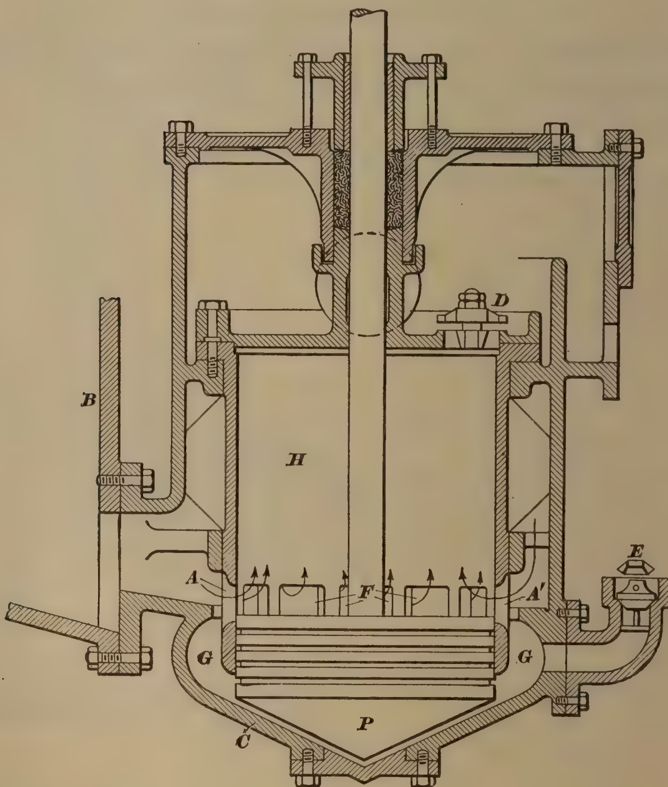

Fig. 11.

The ports *F* connect with the space *G*; and when the piston has closed the port opening *A*, on its down stroke, the water confined in *G* is forced upward with high velocity through the ports *F* and into the cylinder *H*. This accelerates the flow of water and air from the condenser *B*; and when the bucket closes port *A* on the up stroke, it lifts the confined water, and forces it out through the delivery valve *D*. *E* is a relief valve, which opens in case the pressure become too great in chamber *G*.

It will be noted that there are no suction valves, the water flowing by gravity from the condenser B into the pump. When the descending bucket first uncovers the upper part of port A, air rushes into chamber H, and as the opening enlarges, water flows in also. The lack of foot valves and bucket valves greatly minimizes the chances of a breakdown.

POWER PUMPS

POWER PLUNGER AND PISTON PUMPS

23. Uses and Classification.—Power pumps are usually of the vertical, direct-acting type. Their principal advantages are that they can be installed almost anywhere; they are much cheaper than the direct-acting steam pumps of the same capacity; and they are adapted to drives of moderate speed, their action is positive, and they have high efficiency under moderate and high-pressure service. When equipped with ball valves, so as to present an unobstructed opening through the valve ports, they are extensively used for the transferring of heavy stock (stuff pumps) and other dense liquids.

These pumps may be single, duplex, or triplex, the words duplex and triplex here having a somewhat different meaning from that formerly given them in connection with steam pumps. A **duplex power pump** consists of two identical pumps connected to the same shaft that drives the connecting rods, the cranks being placed 180° apart; hence, when one pump is starting its up stroke, the other is starting its down stroke. In the triplex pump, the cranks are placed $360° \div 3 = 120°$ apart; consequently, for every position of the shaft during its revolution, at least one pump is delivering at its maximum capacity. This arrangement reduces the strains and stresses on the pulley shaft and on the belt also, if belt driven; it likewise produces a very even flow in the discharge pipe. These pumps are usually single-acting, because of the difficulties attending the packing of double-acting vertical pumps.

24. Driving the Pumps.—Pumps may be driven by belts direct from the line shaft or from a countershaft. The pulley on the pump is preferably double—a fast and loose pulley—so the pump can be stopped without stopping driving shaft. The speed of

the pump in revolutions per minute may be the same as that of driving pulley; or, it may be reduced as much as 6 to 1 by intermediate gearing. The revolutions per minute of the pump are necessarily limited, rarely exceeding 50 or 60 r.p.m. and usually less; thus the pump pulley can turn at a speed very suitable for driving from moderate-speed motors, steam engines, gas engines, line shafts, etc., and the pump can still run at the low speed for which it was designed.

Other standard forms of drives for power pumps are direct gearing, either simple or compound gears, as may be required to cover the range of speed between the pump crank shaft and the driving source. Silent chain drives may be used, either direct to the crank shaft or with intermediate gears, when required.

25. Description.—A description of a vertical, single-acting duplex power pump used for pumping stuff was given in *Beating and Refining*, Section 3, and the illustration there given is here repeated as Fig. 12, in which (*a*) shows an end and a side elevation, and (*b*) is a section through the pump cylinder to an enlarged scale. As will be seen, ball valves are used on the suction and discharge openings, thus permitting the pump to raise and deliver a thick, viscous liquid, like stuff, even though it may contain solid particles of some size. Referring to (*a*), it will be noted that the cranks are set 180° apart, so that one plunger is beginning its suction stroke as the other is beginning its discharge stroke. Since both pumps have the same suction and discharge pipes, the final effect is exactly the same as would be obtained by a double-acting single pump. It may here be remarked that the general design of the water ends of all reciprocating pumps of the same general type is practically similar in every case, the main difference in this case being the use of ball valves. As shown, the plunger is about to begin its up stroke in view (*b*). It leaves a vacuum behind it, which causes the liquid in the suction pipe to lift valve *F* and flow into chambers *D* and *B*, valve *E* being kept to its seat by the pressure of the liquid above it. An exactly opposite event is occurring in the other pump. There, the plunger is moving down; this produces a pressure on the suction ball valve *F*, forcing it to its seat; and when the pressure becomes greater than that in the discharge pipe, ball valve *E* rises, and the liquid confined in chambers *D* and *B*, or as much of it as is equal to the volume displaced by

the plunger, is discharged into delivery pipe C. Both ball valves are made accessible for inspection by handholes, covered by plates H, which are held tight against gaskets.

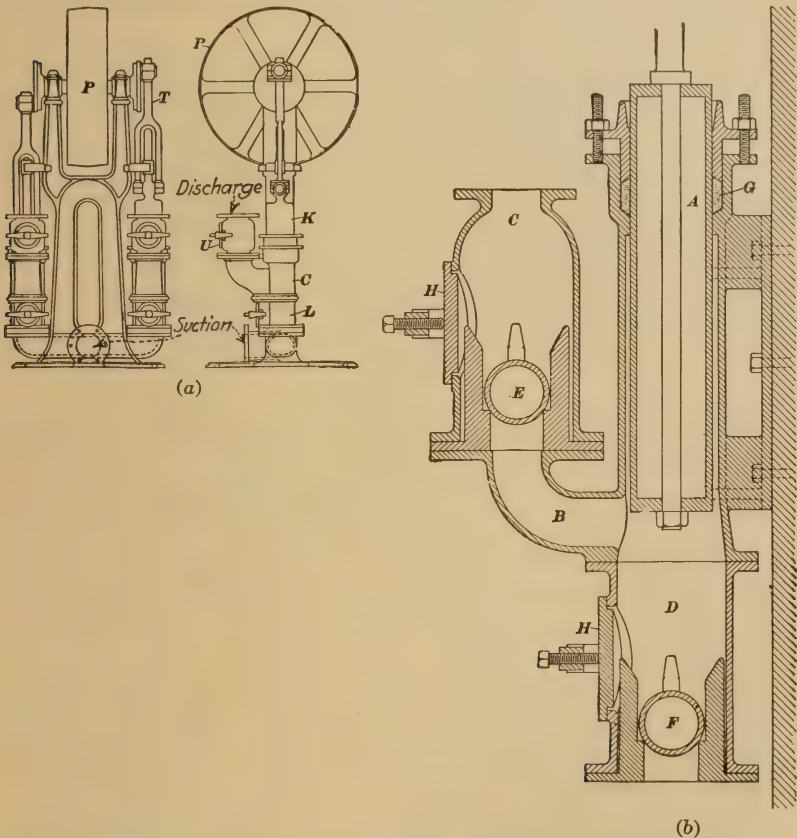

FIG. 12.

26. A simple-geared, vertical, single-acting **triplex power pump** is shown in side and end elevations in Fig. 13. There is a common suction chamber, with two entrances, and a common discharge pipe, connected centrally to the three cylinders. The pulley A is the driving (pump) pulley; it carries a pinion gear on its shaft, which meshes with the large gear wheel B. The latter is keyed to the pump shaft, which drives the connecting rods R', R'', R''', operating the pump plungers, one of which is indicated at P', and which work in the cylinders C', C'', and C'''. The cranks are set 120° apart; hence, when one is about to begin

a down stroke, say, one of the others has completed 120° (two-thirds) of its down-stroke, and the third one has completed 60° (one-third) of its up-stroke revolution. Consequently, there is always a continuous flow of water (liquid) into the discharge pipe.

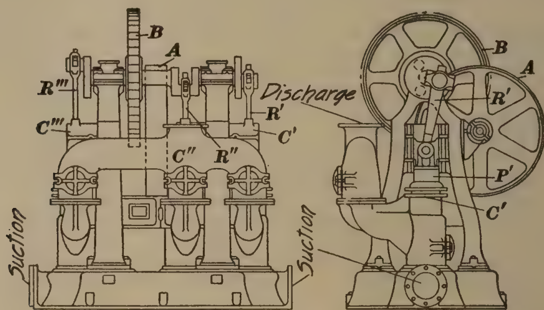

FIG. 13.

27. If it be assumed that gear B has 5 times as many teeth as the pinion that drives it, and the diameter of pulley A is 3 times the diameter of the other belt pulley to which it is connected, there will be a total reduction in speed of $5 \times 3 = 15$ times. These pumps must run quite slowly; hence, if the pump makes 30 r.p.m., the shaft that transmits power and motion to pulley A, the driving shaft, must have a speed of $30 \times 15 = 450$ r.p.m., making no allowance for belt slipping.

Again, suppose an $8'' \times 8''$ triplex pump is to be driven at the rate of 50 r.p.m. from a motor that runs at 1500 r.p.m.; here $\frac{1500}{50} = \frac{30}{1}$; or a reduction of 30 to 1, i.e., 30 times. This is altogether too much for a simple gear reduction, but can be accomplished by a compound gear, sometimes called a double gear reduction. Thus, $\frac{30}{1} = \frac{5}{1} \times \frac{6}{1}$; hence, if one set of the compound gears have a reduction of 5 to 1 and the other a reduction of 6 to 1, the pump may be driven by connecting it direct to the motor. Designate the first set of gears by A and B, the second set by C and D, and suppose gear A to be on the motor shaft. Gear B, which meshes with gear A will be on a follower shaft, which also carries gear C; gear D will mesh with gear C and will be on the pump shaft, which drives the pump plungers. Gears A and C may be equal; assuming that they have 16 teeth each,

gear B must have either $16 \times 5 = 80$ or $16 \times 6 = 96$ teeth, and gear D must have either $16 \times 6 = 96$ or $16 \times 5 = 80$ teeth, respectively.

ROTARY PUMPS

28. Definition and Principles.—As might be inferred from the name, a **rotary pump** is one in which the piston or pistons revolve, instead of having a reciprocating straight-line motion, as in the pumps previously described. In most rotary pumps now in use, there are two pistons, called **impellers,** which revolve in opposite directions, and which are always in contact with each other. These impellers alternately cut off a space previously in communication with the supply (suction) pipe, filled with a fluid (liquid or gaseous), which the impeller forces out through the discharge opening and into the delivery pipe.

29. Description.—An interior view of a popular make of rotary pump is shown in Fig. 14, the casing cover having been removed.

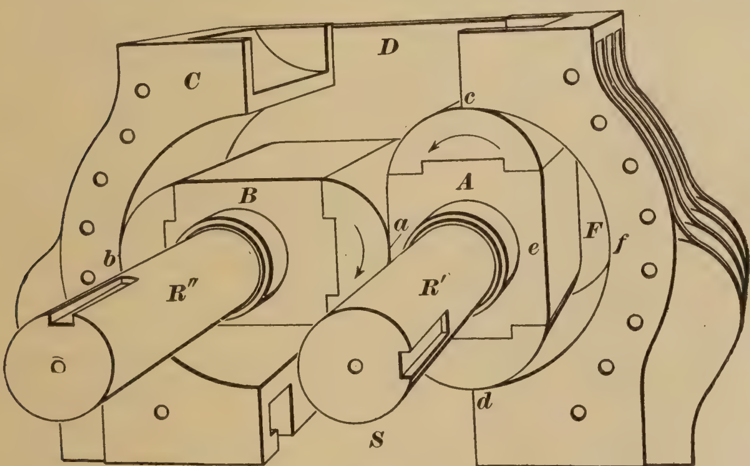

Fig. 14.

The casing C contains the impellers A and B, which are set at right angles to each other. The shafts R' and R'' are connected by equal spur gears, and one of the shafts is driven by a belt or motor; consequently, both shafts make the same number of revolutions per minute and are always in the same relation to each other. The impellers have semicircular ends and straight sides, and are always in rolling contact with each other. Also,

the extreme point of either impeller is always touching the casing; but, since no pressure is exerted against the casing, there is practically no wear and no friction. The suction opening is shown at S and the discharge opening at D; there are no valves.

Suppose the impellers to be turning in the direction indicated by the arrows and to have reached the position indicated in Fig. 14. The space F, whose volume is the area *cedfc* times the width of the impellers, is here entirely shut off from both suction and discharge; and by a further revolution of impeller A, the volume of fluid contained in F is forced out through the discharge opening D. By the time A has made a quarter turn, impeller B will be in the same relative position as A is in the illustration; and any further turning of B will cause a discharge from the other side. By the time A has made a half revolution, it will have trapped another volume of fluid equal to the space F, which is discharged during the second half of the revolution. Since impeller B is doing the same thing in its revolution, it follows that for one complete revolution of the pump, *i.e.*, one revolution of R' or R'', whichever is the driving shaft, four times the volume of space F is drawn through S and discharged through D; the result is a continuous and even flow in the delivery pipe.

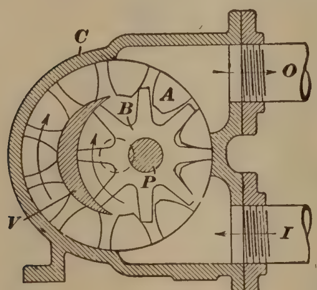

FIG. 15.

30. A Novel Pump.—In Fig. 15 is shown an ingenious and useful construction that has but two moving parts, the annular gear, or rotor A, and the small internal gear, or idler B. The rotor A fits closely inside the casing C, its shaft extending through one side of the casing and carrying the pulley or coupling that drives the pump. The idler revolves on the ground hardened-steel pin P, projecting in from the other side of the pump casing. When assembled, the small gear, or idler, fits into the rotor A. The two gears mesh at a point in the casing midway between the ports O and I, thus forming an absolute barrier to the water drawn in at I, which is entrained between the teeth of both gears; the water is thus forced out through the discharge port O. The vane V is just cleared on one side by the rotor A and on the other side by the idler B; it serves to confine the water (or other fluid) between the teeth of the gears. Since the gears can revolve

in either direction, either port may be used for suction. It is claimed that this pump has very efficient suction-lift properties, and that foot valves are not necessary on ordinary lifts. It is also claimed that this pump will handle air and water at the same time, and that it may be used to advantage on installations where there is considerable gas.

31. Uses and Advantages.—The rotary pump is a very useful member of the pump family, because it can be used successfully under conditions to which other types of pumps are not well

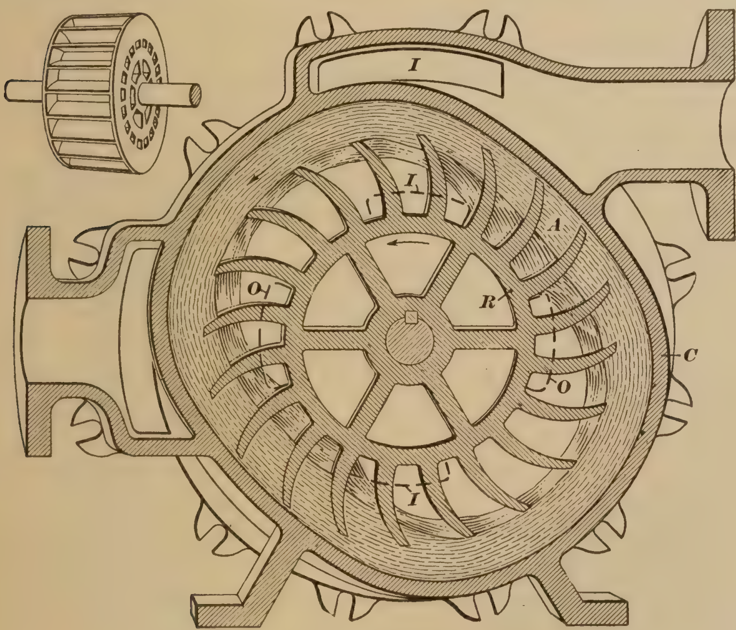

FIG. 16.

adapted. For instance, it will handle thick, viscous, stringy liquids that must be delivered at low velocities, such as heavy crude oil, moderately hot tar, greases, and similar liquids and semi-liquids. Most rotary pumps are suited to being operated at moderate rotative speeds; on this account, they must be belt driven or geared to standard speed motors. For this and other reasons, their field has been encroached upon to a large extent by pumps of the centrifugal type. But, in recent years, several new types of rotary pumps have been developed that are especially suited to condenser work and other classes of service where

the attainment of a high vacuum is essential. These pumps are built strictly for vacuum service—they are not adapted to high-pressure conditions.

An important feature of the high-vacuum pumps just mentioned is the sealing of the valves and clearance spaces by retaining for this purpose a part of the liquid that is handled by the pump. In the case of "dry vacuum" pumps, which are intended for handling only air and vapor, a sufficient quantity of some liquid—such as water—may be circulated through the pump with the vapor for the purpose of sealing the clearance spaces, and thus assisting in the production of the high vacuum required for efficient operation. It should be understood that any such circulating liquid used for sealing purposes is kept continually in the pump; it does not pass out of the discharge with the air and vapor.

32. Centrifugal Vacuum Pumps.—The principle of operation of a pump frequently used to produce a vacuum on paper machines is shown in cross-section in Fig. 16. A rotor R (see perspective in upper left-hand corner), consisting of a circular casting having projecting curved blades, is caused to revolve in an elliptical casing C, which is filled with a liquid, usually water. As the rotor turns, the water turns with it, following the casing because of the centrifugal force. Twice in each revolution, the water alternately recedes from and re-enters the casing, due to the shape of the casing. The water, acting as a piston, compresses the air.

Beginning at A, Fig. 16, the rotor blades are full of water. As the rotor advances, counterclockwise as shown by the arrows, water is thrown out into the casing, drawing air in through the inlet ports I, located in the side of the casing and indicated by dotted lines, thus creating a vacuum. As the rotor blades advance, the inlet ports are passed, and the air is trapped between the blades of the rotor and the surface of the water. The converging casing now forces the water back into the rotor, and the water, acting as a piston, gradually compresses the air. When the air has been brought to the discharge pressure (usually atmospheric pressure in a vacuum pump), the outlet ports O, which communicate with the pump outlet, are reached. The water continues to enter the rotor, driving out the air, and filling the space between the rotor blades. The entire operation is now repeated in the second half of the revolution.

To take care of the heat of compression, a small quantity of water is introduced, if required, at the pump suction with the air. This water, together with any additional liquid coming in with the air, is discharged through the outlet ports. Since the water in the pump casing stays at the level of the outlet ports, the right amount is always maintained in the casing.

Where the white water is to be discharged against a head, a centrifugal-pump runner is mounted on the same shaft, and is fed by the overflow from the suction-pump casing. This arrangement is shown in Fig. 16*a*.

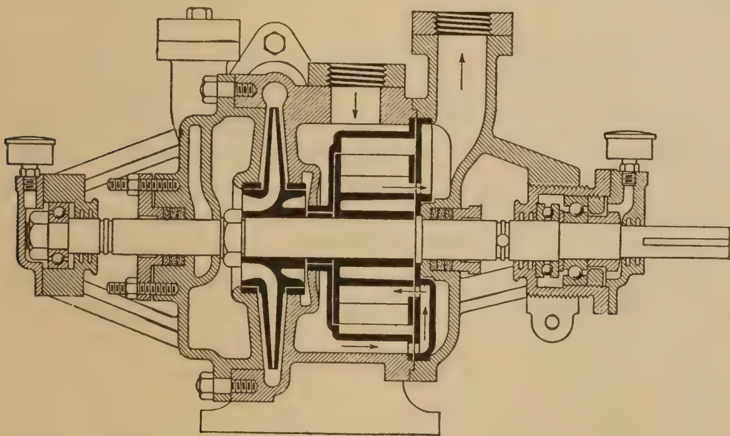

FIG. 16*a*.

These vacuum pumps are at their highest efficiency at vacuums ranging from 12 to 18 inches of mercury; the maximum vacuum is from 21 inches, in the smallest pumps, to 23 inches, in larger sizes. The vacuum is free from pulsation. The air is drawn into five or six rotor spaces simultaneously; and before one is filled, another begins to take air. This results in a continuous flow of air into the machine, producing a constant vacuum.

CENTRIFUGAL PUMPS

33. Principle of Action.—The volume discharged by any of the pumps heretofore considered depends (theoretically), for any one pump, only on the speed of the piston, impeller, or rotor, and is independent of the head against which the pump works. In the centrifugal type of pump, the head against which the pump

works and the volume discharged both depend upon the velocity of the impeller. By **working head,** or head against which the pump works, is meant the total height through which the liquid is lifted plus the height (head) that would just balance the frictional and other resistances to the flow. The volume of discharge and the head bear a separate and distinct relation to the speed of the impeller, and neither can be separated from the other. The name, **centrifugal pump,** is given to this type for the reason that centrifugal force, or change of pressure due to rotation, is the most important factor in the operation of these pumps.

34. Description.—A centrifugal pump in its original and simplest form consists of a casing, or shell, within which revolves an **impeller,** sometimes called the **wheel** or **runner.** The impeller, which is keyed to the driving shaft, carries a series of **vanes,** which extend from and are a part of the hub; were these vanes straight and radial, they would resemble the spokes of a wagon wheel, except that instead of being inserted in the hub, they would be extensions of it. Fig. 17 shows two sections at right angles to each other of a simple centrifugal pump; the right-hand view is a section through the axis of the shaft S, and the other view is a section at right angles to it in the middle plane of the casing. The casing is denoted by C and the vanes by I. The liquid enters the pump at A, the center of the impeller, which is rotating rapidly, and is given a rotary movement by the pressure of the vanes. The peripheral speed of any point of the vane is directly proportional to its distance from the axis of the shaft; this causes the liquid to flow along the vane with ever increasing speed until it is discharged by centrifugal force into the casing, from whence it is forced out of the pump through the discharge outlet D. The large arrow f near the top of the impeller indicates the direction of rotation, which is clockwise; the smaller arrows show the course of the liquid from the inlet A to the outlet D.

35. Theory of Operation.—While the liquid is passing from the inlet to the outside of the impeller, it is receiving energy from the impeller vanes, with the result that both the velocity and the pressure of the liquid are increased. When the liquid is discharged from the impeller into the casing, a large proportion of the energy it has had imparted to it by the vanes is energy due to its velocity, or kinetic energy. A part of this kinetic energy

must be conserved as the liquid leaves the impeller, in order to obtain the desired volume of discharge; the remainder is transformed into pressure in the casing. An efficient pump is dependent very largely on the proper design of the casing, so this excess kinetic energy may be converted into pressure with as little loss as possible.

36. Shape of Casing and Vanes.—Referring to Fig. 17, it will be observed that the curve of the casing is not a circular arc, but a **volute,** or spiral. In the early designs of centrifugal pumps, the casing was concentric with the circle described by the

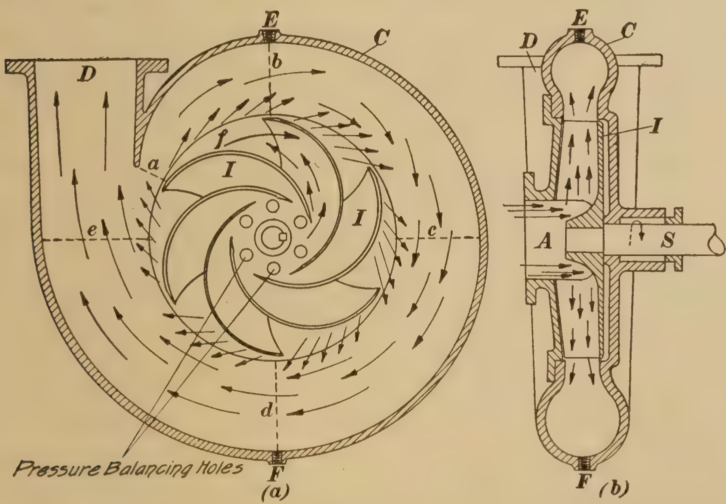

FIG. 17.

extreme points of the impellers, and there was no change in the cross-sectional area between the casing and the impeller; this resulted in a constantly changing velocity as the liquid was driven through the casing. The volute construction provides for a constantly and gradually increasing area of cross-section toward the discharge opening D, as indicated by the lengths of the dotted lines a, b, c, d, e, which gradually increase from a to e. As a result of this change in area, the liquid flows at a practically constant rate; this prevents the formation of eddy currents and the shock losses due to sudden changes of velocity, thus increasing the efficiency of the conversion of kinetic energy into pressure.

The volute form of casing was the first important improvement in the design of centrifugal pumps; another great improvement

was effected when the vanes were given a backward curvature, instead of making them straight and radial. This backward curvature enables the designer to alter and control the velocity of the liquid as it passes through the impeller; it also enables him to provide for proper inlet and outlet angles in order to meet certain pumping conditions. The shape of the vanes may be made such that the liquid will follow a natural path through the impeller with the least amount of frictional resistance.

37. Diffusion Vanes.—It was formerly considered necessary to insert stationary vanes between the impeller vanes and the inside surface of the casing; these are called **diffusion vanes,** and their purpose is to form passages of proper area and angular direction to carry the liquid from the impeller outlet to the casing proper, and to secure an efficient reduction of velocity and change into pressure while passing between these two points. The stationary vanes do increase, to a limited extent, the efficiency, as compared with certain pumps without diffusion vanes; but this increased efficiency is obtained only under certain conditions of capacity (volume of discharge) and head pumped against, and it is not secured over the entire range of capacities and heads under which a centrifugal pump is usually required to work. This increase in efficiency is obtained at a greater first cost for the pump and at a higher cost for upkeep and repairs due to wear and corrosion of the stationary vanes; consequently, the majority of manufacturers do not put diffusion vanes in their pumps, except in special cases that demand extreme efficiencies, and when pumping conditions are practically constant.

38. The Suction Inlet.—Referring again to Fig. 17, note that the liquid enters the impeller inlet in a direction parallel to the shaft. The result is that the liquid must be picked up by the impeller while the liquid is traveling at right angles to the plane in which the impeller rotates. There is also a difference between the velocity of the liquid in the suction pipe and the peripheral velocity of the impeller at the point where the liquid strikes it. This results in a shock or inlet loss, which is caused by the change in direction of motion of the liquid and the change in its velocity.

39. Priming the Pump.—As will be more fully explained later, all centrifugal pumps must be *primed, i.e.,* filled with the liquid to be pumped, before the pump can be started to working. In

Fig. 17, E is a connection for this purpose. The casing can be drained at F, if desired.

40. Classification.—Centrifugal pumps may be classified in five divisions, each of which has two subdivisions, as follows:

First, according to their casings, as (*a*) volute or (*b*) turbine; second, according to number of casings, as (*a*) single stage or (*b*) multistage; third, according to their inlets, as (*a*) single suction or (*b*) double suction; fourth, according to their impellers, as (*a*) open impellers or (*b*) enclosed impellers; fifth, according to their shafts, as (*a*) horizontal or (*b*) vertical. Each of the foregoing types will now be discussed, and in the above order.

41. Turbine Pumps.—These belong to the first division, subdivision (*b*); it is not necessary to consider subdivision (*a*), as this has already been discussed, and is illustrated in Fig. 17.

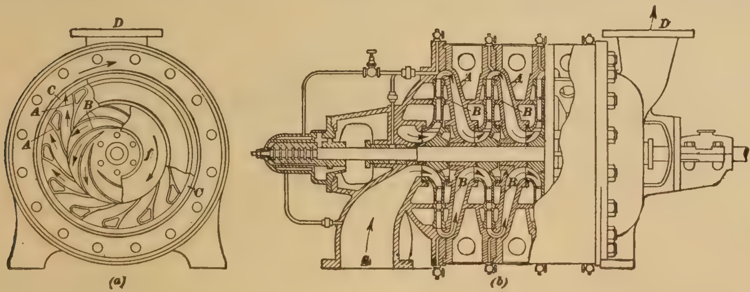

FIG. 18.

The casing of the turbine pump is usually concentric with the impeller, and the cross-sectional area between the casing and impeller is constant, though in some cases, the casing is of the volute type. The distinguishing feature of the turbine pump is the stationary diffusion vanes between the impeller and the free water way of the casing. A partial longitudinal and vertical section of a three-stage (see Art. **43**) turbine pump is shown in Fig. 18. The diffusion vanes are indicated by A, the impeller vanes by B, the free waterway by C, the suction inlet by S, and the discharge outlet by D. The arrows in view (*a*) indicate the direction of travel of the liquid through the impeller, the diffusion vanes, and to the discharge. The arrow *f* indicates the direction in which the impeller turns, which is clockwise in this case.

These pumps are called **turbine pumps** because of their resemblance in construction to the reaction type of water turbine wheel.

There was, and possibly still is, an impression that the turbine pump is different in type from the simpler form, which has no diffusion vanes; such however, is not the case, since the theory of action and the operating characteristics are similar for both types. The diffusion vanes are introduced only for the purpose already mentioned (Art. **37**), and they do not necessarily change the shape of the curves for pump characteristics.

42. Single-Stage Pumps.—A **single-stage** pump has but one casing, in which is developed the pressure required to overcome the total head against which the pump works; it usually has, also, but one impeller, and may be either of the volute or turbine type. These pumps are suited to operating against heads ranging from very low to moderately high; but they are well suited for heads ranging from 0 to 150 feet, though best results are obtained for heads less than 100 feet.

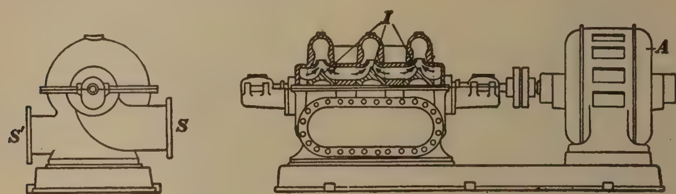

FIG. 19.

A single-stage pump with three impellers, called a **trirotor** pump, is shown in Fig. 19. The three impellers *I* are all of the same construction, are mounted on the same shaft, and rotate in the same casing *A*. There are two suction inlets *S* and *S'*, which deliver liquid at the same pressure and velocity to all impellers, and the discharge pipe is common to all three impellers, being connected to a common discharge chamber. Pumps of this kind are called **multirotor pumps,** and may have two, three, or more impellers. The object of using more than one impeller is to secure higher rotative speeds, since the impellers may be of smaller diameter for the same discharge and head, therefore, the capacity and head obtained are equivalent to that of two or more pumps operating in parallel.

43. Multistage Pumps.—When several pumps, having their impellers all mounted on the same shaft, are connected in series, so the discharge from the first enters the suction of the second, the discharge from the second enters the suction of the third,

and so on, the discharge from the last entering the delivery pipe, the whole constitutes a **multistage pump.** The head, or pressure, developed by the first impeller, is transmitted to the second impeller, which, in turn, develops an equal additional head, or pressure, and transmits it to the third, and so on. All the impellers have the same diameter and peripheral speeds; hence, the total head, or pressure, developed will be as many times that developed by the first impeller as there are impellers. Such a pump having two impellers is called a **two-stage pump,** one having three impellers is called a **three-stage pump,** etc. For instance, suppose a three-stage pump to have impellers of such characteristics and speed that each will develop a head of 125 feet and deliver its normal amount; the pump will then deliver this same amount against a head of $125 \times 3 = 375$ feet.

A diagrammatic section of a three-stage centrifugal pump is shown in Fig. 20. S is the suction inlet, D is the discharge outlet,

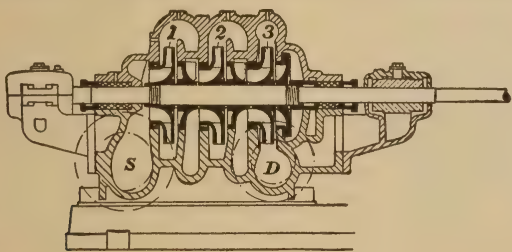

FIG. 20.

and the impellers in their order, are denoted by 1, 2, and 3. The connections between the several casings are not here shown, but may be pipes leading from the discharge of the first casing to the "suction" of the second, etc. Note that the width of the several casings decreases as the head increases, that for casing 3 being the smallest. A multistage turbine pump was shown in Fig. 18, the arrows in view (*b*) showing the course of the liquid through the pump.

44. Single-Suction Pumps.—**Single-suction,** or **single-inlet,** pumps have an opening to the impeller on one side only, as A, Fig. 17 (*b*). All pumps of this class have an unbalanced area, which is equal to the difference between the area of the suction opening and the area of the shaft S. This is called an **unbalanced area** because the pressure on the left, or suction, side is less than that on the right side, which is subjected to the pressure of the

discharge. Hence, if A be the area of the suction opening, a the area of the shaft S, p the pressure at the suction opening, and P the discharge pressure, the unbalanced pressure U is

$$U = (A - a)(P - p),$$

and this exerts a force, or thrust, that tends to push the impeller and shaft to the left, *i.e.*, toward the suction opening. A pump having excessive thrust, and not provided with means for counteracting and absorbing the thrust, will not operate satisfactorily. The thrust causes the impeller to rub against the casing, and also causes overheating of, and excess wear on, the thrust bearing; the result is increased power consumption and lowered efficiency. As a consequence, means should always be provided for taking care of the end thrust.

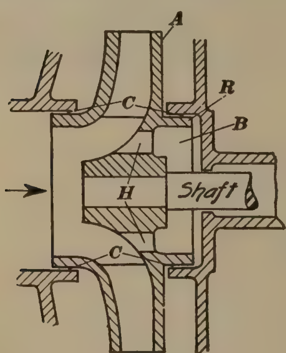

FIG. 21.

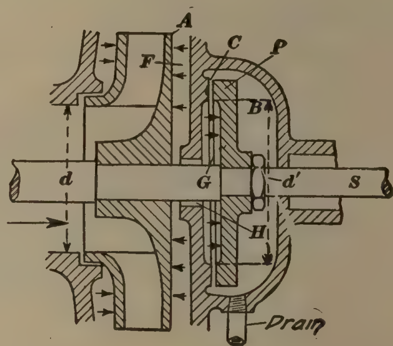

FIG. 22.

45. The End Thrust.—The end thrust may be taken care of in three ways:

First, by means of a thrust bearing of suitable design and ample strength, to absorb the entire thrust of the impeller. This method is not considered good practice.

Second, by means of a balancing chamber, in the casing and behind the impeller, in combination with a ring that is cast on the impeller and has a small running clearance; in addition, there should also be a thrust bearing to absorb the thrust not taken care of by the balancing chamber. This device is shown in Fig. 21, where A is the impeller, B the balancing chamber, R the ring, and C the running clearance. The outside diameter of the ring (plus the clearance) is the same as that of the suction opening; hence, if it were not for leakage through the clearance space, there would be no unbalanced area. To prevent a

building up of pressure on account of leakage through the clearance space, holes *H* through the central web of the impeller release this pressure back into the suction chamber.

Third, by balancing, hydraulically, the end thrust through counterpressure. The usual and most effective way of accomplishing this is by means of a balancing piston or disk, mounted on the pump shaft behind the impeller, as shown in Fig. 22. Here *A* is the impeller, *S* the impeller shaft, and *P* is the balancing piston, or disk, keyed to the shaft *S*. A chamber *B* is cast on the casing, behind the impeller. The shaft *S* can move slightly along its axis, and when it moves, it carries the impeller and the balancing piston with it. When the balancing piston *P* moves to the left, it uncovers ports leading to the space *F*, which is subjected to the discharge pressure, with the result that the water (or other liquid) in *F* flows into the chamber *B*, into the clearance space *C*, and exerts a pressure on *P* that tends to force it to the right. The width of the clearance space *C* becomes very small, so that only a small amount of water can enter the space *G*. It will be noted that the diameter d of the suction opening is a little smaller than the diameter d' of the space *G*; the pressure on the excess area of the surfaces (projected areas) having these diameters is required to move the shaft. The device operates as follows: when the unbalanced pressure causes the impeller to move to the left, it uncovers the ports communicating with *B*, and water at discharge pressure fills the clearance space *C*; the greater pressure then acting on piston *P* forces the piston shaft, and impeller to the right, until there is a perfect balance and the impeller remains stationary. The result is the same as though a force were pushing to the right on *P* and to the left on *A*, and these forces (indicated by the little arrows) had become equalized.

Any leakage that occurs past the clearances is, of course, a loss, and it causes a loss of efficiency in the pump; however, under favorable conditions, this loss may be less important than the power that would be absorbed by a thrust bearing. The leakage is usually carried away to the suction by a by-pass. With a hydraulically balanced type of pump, a thrust bearing is never used—it is entirely unnecessary. This device is effective and fairly durable when handling water that does not have corrosive properties. But when the water has corrosive chemical properties or deposits scale, as is frequently the case with hot water for

boiler feeding, the deposit of scale will render the device ineffective for balancing purposes; the deposits of scale will open up the clearance to such an extent that a large percentage of the water handled by the pump will be by-passed from the balancing chamber to the suction, materially reducing the discharge and the efficiency of the pump.

46. Double-Suction Pumps.—In the case of double-suction, or double-inlet, pumps, the liquid enters the impeller at either side, and through openings of equal area. Theoretically, there is no unbalanced area on either side of the impeller. The original double-suction pumps, designed when centrifugal pumps were used only for low heads and moderate speeds, were not equipped

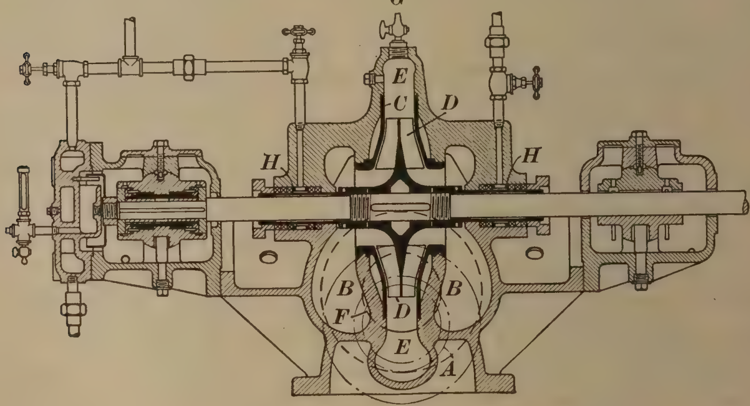

FIG. 22a.

with thrust bearings, and they gave very good results. With the present high speeds and heads, however, it has been found advisable to have a small thrust bearing, since it is practically impossible to secure foundry and machine work of sufficient accuracy to prevent a slight amount of thrust.

With a few exceptions, such as handling heavy or fibrous paper stock, the double-suction type of centrifugal pump is practically ideal for all pumping conditions. The suction being divided, the openings into the impeller are of smaller diameter than in the case of single-suction pumps; consequently, the impeller is of smaller diameter and it runs at a higher speed than a single suction pump under the same conditions of discharge and head. These features reduce the susceptibility to scale and corrosion in these pumps.

Fig. 22*a* shows a sectional view of a double-suction centrifugal pump. Here *A* is the suction pipe flange; *B*, *B* the suction ports; *D* is the impeller; *C*, *C* are renewable guide plates; *E* is the volute-shaped discharge passage; *F* the discharge pipe flange; *H*, *H* are water seals; and *G* is a pet cock.

47. Open Impellers.—The fourth division includes the open impeller and the closed impeller types. Open impellers are those in which the vanes are supported from the central hub, as in Figs. 17–22. The liquid passing through the impeller is in contact with the inner surfaces of the casing that confines the impeller. This is the original design of impeller, and it is fairly efficient under low heads. It is also suited to handling fibrous material, such as sulphite pulp; but the slippage past the vanes at the clearance between them and the casing, and the extra friction of the liquid passing through the casing, reduce the efficiency of this type of impeller. Such losses are bound to increase as these clearances become larger through wear.

48. Enclosed Impellers.—The vanes in enclosed impellers are supported from the central hub and are also enclosed, or shrouded, at both sides by flat surfaces, thus making a closed passage way for the liquid as it flows through the impeller; the liquid does not come into contact with the sides of the casing. With this type, slippage can occur only at the running clearance space surrounding the suction inlet to the impeller. Although wear will increase this clearance, in most designs, the clearance ring can easily be replaced by a new one whenever deemed advisable, and the efficiency of the pump is again brought back to normal. In pumps of high efficiency, the impellers are customarily of the enclosed type; they are made of bronze, and the inner and outer surfaces are machined and polished to reduce the friction to the smallest possible amount. Pumps of either open or enclosed type of impeller may be single or double suction.

49. Horizontal Pumps.—The fifth division includes horizontal and vertical pumps. The pumps previously described are all of the horizontal type; that is, their shafts are in a horizontal position. This is the most common form of centrifugal pump, and it is always installed when conditions will permit.

50. Vertical Pumps.—A vertical pump is one that runs with its shaft in a vertical position. They are used only in cases where it

is necessary to submerge the pump below the surface of the liquid to be pumped, where it is necessary to set the pump end below the motor or driving pulley in order to get within the suction limits of the liquid to be pumped, or to prevent the motor from being flooded by a rise in water level. Vertical pumps may be entirely submerged, in which case, they should be equipped with suitable bearings for this purpose; or, they may be set either above the water level on the suction side or else located in dry wells, so as to be accessible.

51. Reasons for Priming Centrifugal Pumps.—As stated in Art. **39**, it is necessary to prime a centrifugal pump before it can be started to working. By **priming a pump** is meant to fill it with water or whatever liquid is being pumped. Priming is necessary because there is a free waterway through the entire pump, and at no period in the revolution is the suction opening closed off from the discharge opening. Therefore, in an unprimed pump, positive displacement of the air cannot occur; the air in the pump is simply churned around in the impeller and clearance spaces, and is not drawn out of the suction pipe by the formation of a vacuum. By first filling the pump with the liquid to be pumped, the discharge of this liquid creates the necessary vacuum and starts the flow of liquid into the pump.

52. Methods of Priming.—There are five general methods of priming a centrifugal pump, as follows:

(*a*) By placing the pump below the level of the liquid to be lifted; either by submerging the pump in the liquid or by setting the pump in a pit or depression, so the liquid will flow into the pump and fill it.

(*b*) By locating the pump at the side of a tank that holds the supply of liquid to be pumped, the level of the liquid in the tank being higher than the top of the pump before it is started up. This is the method that is usually employed in paper-mill practice.

(*c*) By placing a foot valve at the lower end of the suction pipe, and filling the pump and suction pipe with water from any available supply before starting the pump.

(*d*) By connecting an ejector (see Art. **54**) to the high point of the pump casing; this will draw the air out of the pump and suction pipe, producing sufficient vacuum to allow the atmospheric pressure to raise the water level within the pump to a height

sufficient to fill it. Steam, compressed air, or water under pressure may be used to operate the ejector.

(*e*) By means of an air pump connected to the high point of the pump casing; this draws out the air from the pump casing and suction pipe, with the same results as by method (*d*).

53. Height of Suction.—A centrifugal pump, when properly connected, will raise water to as great a height by suction as any other type of pump; in fact, they may usually be depended upon to operate with suction lifts somewhat higher than can be had with pumps equipped with suction valves. When a centrifugal pump is once started, the flow through the suction pipe is continuous; it is not intermittent or periodic with the opening and closing of the suction valves, and no part of the atmospheric pressure that causes the flow through the suction is expended in opening the valves. Though the amount of pressure so used is small, it nevertheless decreases the suction lift by that amount, and it will make the suction lift of the centrifugal pump just that much greater. However, it is not advisable to arrange pumping installations with extremely high suction lifts, because slight leaks in the suction pipes and stuffing boxes are always liable to occur, and suction troubles are often hard to overcome in any type of pump (see Art. **81**).

EJECTORS

54. Principle.—**Ejector pumps** differ from all those heretofore considered in that they have no moving parts; they depend for their action upon the movement through them of a fluid (which may be a liquid, gas, or vapor), which flows through the pump at a high velocity and carries the discharge with it. They are largely used for priming centrifugal pumps, and may be and are used as suction pumps. The ejector has recently been applied to the evacuation of paper-machine dryers.

55. Description.—A sectional view of an ejector is shown in Fig. 23. The fluid used for operating the ejector (steam, water, or compressed air) flows through the expanding nozzle *A*, which is contained in the chamber *B*; it enters the nozzle at a high velocity, and as it leaves the nozzle outlet, it expands, completely filling the pipe ahead of it with fluid or vapor under pressure. It drives ahead of it any water or air that may be in the pipe

through the discharge nozzle C, and thence through the discharge pipe. The air or water thus displaced is replaced by air or water or other fluid, drawn up by suction through the pipe D, to fill the vacuum thus created in chamber B. The flow from the ejector discharge is steady, the air or water that is forced through the discharge pipe mingling with the steam, water, or compressed air used for operating the pump.

On account of the manner of its action, the operating pressure is reduced nearly to atmospheric pressure when the fluid leaves the nozzles; consequently, the ejector pump cannot be used for pumping against heads of more than a few feet above the pump itself. It is customary to use them for pumping and priming service, and they are so arranged that there will be a discharge to the atmosphere with practically no discharge head.

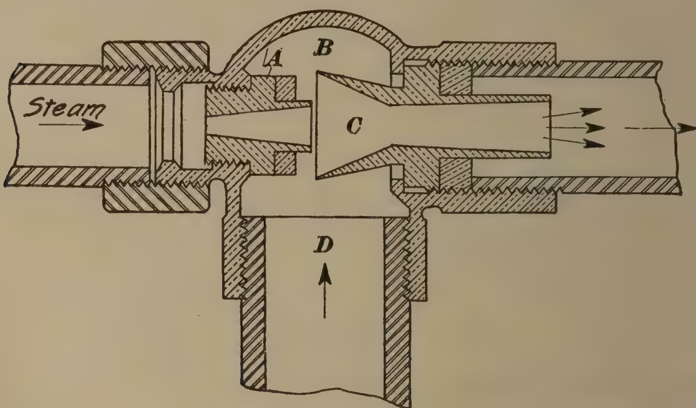

Fig. 23.

PUMP CALCULATIONS

CAPACITY OF PUMPS

56. Piston Displacement.—The **piston displacement** is the volume swept through by the piston in moving a certain distance or during a certain time, usually the volume displaced in one stroke or in one minute. The displacement per stroke is equal to the area of a cross section of the cylinder multiplied by the length of the stroke. (It is always understood that by *cylinder*, in this case, is meant the area of the cross section of the surface touched by the outside of the piston or plunger, and whose length is equal to the length of the stroke, regardless of its actual length,

which is greater than the length of the stroke by the amount of the clearance.) If the displacement is desired in cubic feet, let D = the diameter in feet, L = stroke in feet, V' = displacement (volume) in cubic feet; then,

$$V' = 0.7854D^2L \qquad (1)$$

If the diameter of the cylinder and the length of the stroke are taken in inches, they may be denoted by the corresponding small letters, and

$$V' = \frac{0.7854d^2l}{1728} = 0.000454514d^2l \qquad (2)$$

Or, if v' = the displacement in cubic inches,

$$v' = 0.7854d^2l \qquad (3)$$

Since there are 231 cubic inches in 1 gallon, the displacement in gallons per working stroke is, letting G' = the number of gallons,

$$G' = \frac{0.7854d^2l}{231} = 0.0034d^2l \qquad (4)$$

In a single-acting pump, the number of *working strokes* is the same as the number of revolutions, or one-half the total number of strokes; in a double-acting pump, the number of working strokes is twice the number of revolutions, and equals the total number of strokes. Let N = the number of working strokes per minute; then, the piston displacement in cubic feet per minute is

$$V = 0.000454514d^2lN, \qquad (5)$$

and in gallons per minute,

$$G = 0.0034d^2lN, \qquad (6)$$

V and G being cubic feet per minute and gallons per minute, respectively.

Example.—What is the plunger displacement of a double-acting plunger pump having a stroke of 12 in., the diameter of the plunger being 14 in. and the number of strokes per minute 66?

Solution.—Evidently the displacement per minute is wanted, since the number of strokes per minute is stated. Applying formula (5),

$V = 0.000454514 \times 14^2 \times 12 \times 66 = 70.56$ cu. ft. per minute. Ans.
Or, $G = 0.0034 \times 14^2 \times 12 \times 66 = 527.8$ gal. per minute. Ans.

57. Pump Capacity.—By **pump capacity** (or capacity of a pump) is meant the displacement of the water piston or plunger; it may be stated in cubic feet per stroke or per minute, or in gallons per stroke or per minute. Manufacturers rate their pumps in gallons per minute, the capacities so stated being the same as those calculated by formula (6).

The capacity as thus calculated is the **theoretical capacity**; it is not the same as the actual discharge of the pump, or **actual capacity**, because of slippage of water past the valves, and because, in double-acting pumps, the volume occupied by the piston rod on one side or stroke should be deducted. The quotient obtained by dividing the actual capacity, as determined by test, by the calculated theoretical capacity is called the **volumetric efficiency**; it is usually expressed as a per cent. For instance, if the calculated capacity of a pump is 528 gallons per minute, and the actual capacity as determined by test is 496 gallons per minute, the volumetric efficiency is

$$\frac{496}{528} = 0.94 = 94\%.$$

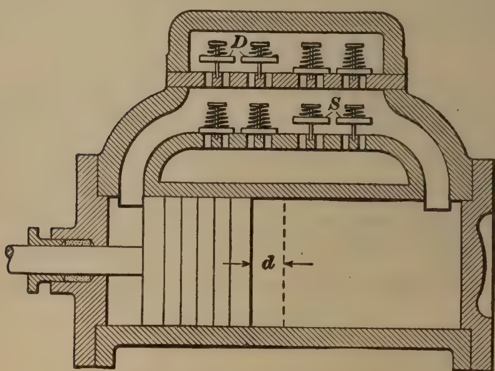

Fig. 24.

58. Slip or Slippage.—The valves, both suction and discharge, do not seat the instant the piston has completed its stroke—and they must remain open until then—because they require a certain amount of time to reach their seats. In consequence, the valves are open for a very short time after the piston has begun the return stroke, and some of the liquid leaks back into the cylinder from the discharge pipe. For low piston speeds, the valves do not lift as far from their seats as in the case of high piston speeds, and since the piston is moving slowly, it does not move so far on its return stroke before the valves have closed. With high speeds, however, the valves lift higher, require a longer time to close, and the piston moves an appreciable distance before the valves are finally seated, as may be seen by referring to Fig. 24. Here the piston has reached the end of its stroke; the

valves D and S are still open, and as the piston begins its movement to the right, water slips past the valves D from the discharge; meanwhile, on the right side of the piston, water is forced back into the suction through the open suction valves S. The piston may move the distance d before the valves are fully seated. The leakage through the discharge valves D is called the **slip,** or **slippage,** and it is always expressed as a per cent of the piston displacement. In high-speed pumps, the slip may be as much as 15% or more, but under low or medium speeds, it averages about 5%. Consequently, the volumetric efficiency may be said to range from $(100 - 5) \div 100 = 0.95 = 95\%$ to $(100 - 15) \div 100 = 0.85 = 85\%$.

Under certain conditions, the pump may run beyond its normal rated stroke; this is called *running over* stroke. This is usually of no disadvantage in pump operation, provided there is ample clearance space between the cylinder heads and the pistons, to eliminate any possibility of the piston striking the cylinder heads; also, there must be sufficient clearance space at the ends of the steam cylinder to secure the proper cushioning effect by the compression of the exhaust steam that remains in the cylinder after the exhaust valves have closed.

59. Capacity of Duplex Pumps.—All the foregoing formulas and statements are applicable to any single reciprocating pump, whether it be a direct-acting steam pump or a power pump. They may also be applied to duplex and triplex pumps by restricting them to one cylinder only, and then multiplying the final result by the number of cylinders—by 2 for a duplex pump and by 3 for a triplex pump. This is evidently correct, since all the cylinders have the same diameter and their pistons the same stroke. It is to be noted, however, that the piston speed of a duplex or triplex pump is always stated in terms of one piston only. Thus, if a triplex pump have a stroke of 10 inches, and it makes 72 strokes per minute the piston speed is $\frac{10 \times 72}{12} = 60$ feet per minute; it is not rated as $60 \times 3 = 120$ feet per minute.

60. Capacity of Rotary Pumps.—The capacity of a rotary pump is not so easily determined as that of a reciprocating pump; it depends upon the design of the pump and the number of revolutions it makes per minute. For the design shown in Fig. 14, the manner of determining the displacement for one revolu-

tion was outlined in Art. **29**, and this multiplied by the revolutions per minute will give the displacement per minute in cubic inches. Thus, multiply 4 times the area trapped by the impeller (in square inches) by the thickness of the impeller in inches, and by the revolutions per minute of the impeller; this result divided by 231 will give the theoretical capacity in gallons per minute. Although these pumps usually have no valves, there is a certain amount of slip between the impellers and the casing, which increases with length of service, on account of wear.

HORSEPOWER OF PUMPS

61. Theoretical Horsepower.—The theoretical horsepower of any machine that uses a fluid (steam, gas, compressed air, water, etc.) for its motive power, or which discharges a fluid (as in the case of a pump, fan, blower, etc.), may be readily found by applying the following formula, in which H = the horsepower, V = the volume in cubic feet per minute of the fluid displaced, and P = the average pressure in pounds per square foot that is exerted on the fluid:

$$H = \frac{PV}{33,000} \qquad (1)$$

If p = the average pressure in pounds per square inch and v = the volume in cubic inches, $P = 144p$ and $V = \frac{v}{1728}$. Substituting these values of P and V in equation (1),

$$H = \frac{144pv}{1728 \times 33,000} = \frac{pv}{396,000} = 0.0000252525pv \qquad (2)$$

Formulas (1) and (2) are perfectly general, and they may be applied to any of the cases mentioned above; when applied to a pump, V is the capacity in cubic feet per minute, and v is the capacity in cubic inches per minute. If G = the capacity in gallons per minute, $v = 231G$; hence, substituting this value of v in formula (2),

$$H = \frac{231pG}{396,000} = 0.00058\tfrac{1}{3}pG \qquad (3)$$

Further, if the delivery pressure be measured as a head of water in feet, and the weight of a cubic foot of water be taken as 62.4 pounds, the pressure per square inch for each foot of head will be $\frac{62.4}{144} = 0.4\frac{1}{3}$ pounds. Then, letting h = the head in feet,

$p = 0.4\frac{1}{3}h$. Substituting this value of p in formula (3),

$$H = 0.00058\tfrac{1}{3} \times 0.4\tfrac{1}{3}hG = 0.00025278hG \qquad (4)$$

Example.—If a pump delivers 528 gal. per minute against a total head (this includes the suction lift) of 120 ft., what is the theoretical horsepower of the pump?

Solution.—Since the head in feet and discharge in gallons are given, use formula (4); substituting,

$H = 0.00025278 \times 120 \times 528 = 16$ h.p., very nearly. Ans.

62. Actual Horsepower.—The actual horsepower is considerably in excess of the theoretical horsepower for a number of reasons: the volumetric efficiency is always less than 100%; power is required to accelerate the moving parts (which is another reason for trying to get a continuous discharge), including the fluid being pumped; the frictional resistances of the moving parts and of the fluid; the resistances at the suction and discharge openings; the resistances due to bends in the pipe, elbows, etc. The result of these conditions is that if a pump is to be ordered that will deliver some particular volume against a head of a certain number of feet, the horsepower that will be required will be from 30% to 60% in excess of the theoretical calculated horsepower that would meet those specifications. The corresponding efficiencies are then $100 \div 130 = 0.769 = 76.9\%$ and $100 \div 160 = 0.625 = 62.5\%$, respectively. The smaller pumps are less efficient than the larger ones, because of the smaller pipes and openings and the proportionately greater friction losses.

63. Influence of Density of Liquid.—Formula (4) of Art. **61** is applicable only when pumping pure water. When pumping other liquids or water containing foreign material, the formula should be multiplied by the specific gravity of the liquid. Representing the specific gravity by s, the formula becomes

$$H = 0.00025278shG. \qquad (1)$$

If the weight of a cubic foot of the liquid is known, then, referring to formula (3), Art. **61**, and letting w = the weight of a cubic foot of the liquid pumped, $p = \frac{wh}{144}$. Substituting this value of p in formula (3) and reducing,

$$H = 0.0000045093whG \qquad (2)$$

Example.—Suppose the liquid being pumped weighs 63.8 lb. per cubic foot; what will be the theoretical horsepower of a pump that is to deliver 750 gal. per min. against a total head of 136 ft.?

Solution.—Substituting the values given in formula (2),

$$H = 0.0000045093 \times 63.8 \times 136 \times 750 = 29.34 \text{ h.p.} \quad \text{Ans.}$$

The frictional resistances to the flow of the liquid greatly increase as the density and viscosity of the liquid increase, particularly with increase in viscosity.

64. Horsepower of Reciprocating Pumps.—The theoretical horsepower of a reciprocating pump may be readily calculated by means of formula (2), Art. **61**, but one of the two formulas given below will be found more convenient. In the formula referred to, $v = 0.7854d^2lN$, where d is the diameter of the pump cylinder, l is the length of the stroke, and N is the number of working strokes per minute. Substituting this value of v in formula (2),

$$H = \frac{p \times 0.7854d^2lN}{396{,}000} = 0.00000198\tfrac{1}{3}pd^2lN \qquad (1)$$

Or, since $p = 0.4\tfrac{1}{3}h$, in which h is the total head,

$$H = 0.00000198\tfrac{1}{3} \times 0.4\tfrac{1}{3}hd^2lN = 0.00000085944hd^2lN \qquad (2)$$

Example.—If the diameter of a pump is 14 in., its stroke is 12 in., the number of working strokes per minute is 66, and the total head is 120 ft., what is its theoretical horsepower?

Solution.—Using formula (2) and substituting the values given,

$$H = 0.00000085944 \times 120 \times 14^2 \times 12 \times 66 = 16 \text{ h.p.} \quad \text{Ans.}$$

65. Efficiency of Power Pumps.—As a rule, the efficiency of a power pump averages quite high; it depends on the pump capacity (size of pump) and the head pumped against. The values given in the following table may be considered as representative of single-acting triplex pumps, when pumping clean fresh water.

Efficiencies of Triplex Pumps (Per Cent)

Capacity in gallons per minute	Total head in feet				
	50	100	150	250	300 and upwards
10	30	35	40	45	50
20	45	55	65	70	75
30 to 100	55	65	70	75	80
150 to 250	60	70	75	80	80
300 and over	65	75	80	85	85

The efficiencies of power pumps having packed pistons may be considered as being 5% less than the values given in this table because of the greater packing friction. Also, pumps handling slush pulp will have somewhat lower efficiencies, on account of the greater viscosity.

To show how the table may be used, suppose it is desired to find what power will be required to operate an 8 × 8-inch triplex pump, single acting, making 55 r.p.m., and working against a total head of 168 feet. Now calculate the capacity, using formula (6), Art. **56,** and

$$G = 0.0034 \times 8^2 \times 8 \times 55 \times 3 = 287.23 \text{ gal. per minute}$$

Since the pump is single acting, the number of working strokes is the same as the revolutions, or 55 per minute. Also, since there are three working cylinders in a triplex pump, it is necessary to multiply the result given by the formula by 3. Referring to the table, the capacity falls between 250 and 300; hence, use the row containing 250 in the first column or column of arguments, because it is safer to use the lower value than the higher one. Since the given head, 168, falls between the columns headed 150 and 300, the value of the efficiency for a head of 168 is (by interpolation) $75 + (80 - 75)\frac{168 - 150}{250 - 150} = 75.9\%$. Now using formula (4), Art. **61,**

$$H = 0.00025278 \times 168 \times 287 = 12.19 \text{ h.p.}$$

Since the efficiency is to be taken as 75.9%, the actual horsepower is $12.19 \div 0.759 = 16.06$ h.p. Ans.

THE SUCTION LIFT

66. Influence of Temperature.—The temperature of the liquid being pumped exerts a very marked effect on the height to which it can be raised by suction. Water, for instance, gives off vapor at all temperatures; but, for quite low temperatures, this can be neglected. The amount and tension of this vapor increase very rapidly with increase in temperature; and the vapor not only occupies space in the pump chamber but it also exerts a counter-acting pressure on the entering water, reducing the suction head by this amount. As the temperature continues to increase, this effect becomes so pronounced as to entirely destroy the suction. Beyond this point, it will be necessary to exert a pressure (head)

on the suction in order to make the water enter the pump. All this is clearly shown by the curves in the following chart, Fig. 25.

Referring to the chart, note that the values along the bottom that start from 0 and increase to the right are the suction lifts in feet corresponding to the water temperatures at the left-hand margin; while those that start at 0 and increase to the left are the heads that must be placed on the suction to force the water into the pump. There are three curves: the full-line curve, marked P, gives the practical suction lift or suction head; the dotted curve, marked M, gives the maximum lift or minimum head under the most favorable conditions; the broken and dotted curve, marked

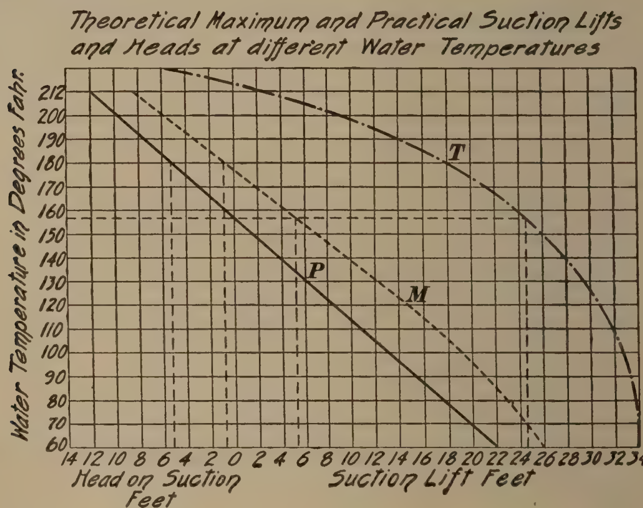

FIG. 25.

T, shows the theoretical suction lift. Thus, for a temperature of 60°, the practical suction lift is 22 feet, the maximum suction lift under the best conditions is 26 feet, and the theoretical suction lift is 34 feet. For a temperature of about 157°, the practical suction lift is 0, the maximum under the best conditions is about 5.3 feet, and the theoretical lift is about 24.7 feet. For 180°, there must be a head on the suction of about 5.3 feet for practical cases, about 0.8 foot for best conditions, while the theoretical lift is 18 feet. The values given by this chart apply only when the pump is situated at sea level and the barometer registers 30 inches or 760 mm., and should be considered approximate in their application to pumps in general.

67. Influence of Altitude.—Since the atmospheric pressure decreases as the altitude increases (see *Physics*, Vol. I), it will be apparent that for any increase in altitude, there will be a decrease in the height of the practical suction lift. For practical purposes, this decrease may be taken as 1.25 feet for each 1000 feet of elevation above sea level. For instance, if the water has a temperature of 60° (which is a fair average) and the pump is situated 5600 feet above sea level, the reduction in suction lift due to altitude is $1.25 \times \frac{5600}{1000} = 1.25 \times 5.6 = 7$ feet. By reference to the chart, Fig. 25, the practical lift for 60° is 22 feet; hence, the practical suction lift at 60° for this altitude is $22 - 7 = 15$ feet.

CENTRIFUGAL-PUMP CALCULATIONS

68. Theory.—It was shown in *Mechanics and Hydraulics*, Part 3, Vol. II, that the height h to which a body having an initial velocity v would rise is given by the formula $h = \frac{v^2}{64.32}$. If the fluid leaving a centrifugal pump were to be conducted vertically upwards, it ought, theoretically, to reach this height, v being the peripheral velocity of the extreme points of the impellers. Solving the above formula for v, $v = 8.02\sqrt{h}$. In these two formulas, h is the head against which the pump is working; and from them, it is seen that the head varies as the square of the velocity, while the velocity varies as the square root of the head. In other words, if the velocity be doubled, the head will be increased $2^2 = 4$ times; but, if the head be doubled, the velocity will be increased only $\sqrt{2} = 1.4142$ times. For example, suppose a pump to make 800 r.p.m., and that it works against a head of 25 feet; if the speed were doubled, increased to 1600 r.p.m., the same pump should, theoretically, work against a head of $25 \times 4 = 100$ feet. But if the head were doubled, the increase in velocity would be $1.4142 \times 800 = 1131$ r.p.m.

69. This relation between the head and the velocity remains practically constant for impellers of normal design; but in practice this relation will vary slightly because of changes in the shape of the vanes, and because of differences in loss of head when operating under various heads. For instance, an impeller design for low speeds and having a rather steep outlet vane angle would, if

operated at high speed, develop a somewhat greater head than an impeller designed for that speed and having the same diameter, though the latter may operate at a higher efficiency. Another condition that has a tendency to vary the relation between the head and velocity is created by the differences in slip at the running clearances, which increase in proportion to the heads pumped against, and which therefore affect the actual heads that a given mpeller will develope at various speeds.

If the speed of a pump be doubled, the capacity is also doubled, theoretically. Referring to equation (4), Art. **61,** it is clear that, since h is increased 4 times and G 2 times, H will be increased $2^2 \times 2 = 2^3 = 8$ times; in other words, the power varies as the cube of the velocity. For example, if a centrifugal pump is delivering 400 gallons per minute against a head of 25 feet, when making 800 r.p.m., the theoretical horsepower will be (formula (4), Art. **61**)

$$H = 0.00025278 \times 25 \times 400 = 2.53 \text{ h.p.}$$

If, now, the speed be increased to 1400 r.p.m., the capacity will be increased $\frac{1400}{800} = \frac{14}{8} = \frac{7}{4}$ times; the head will be increased $(\frac{7}{4})^2 = 3.06$ times, to $25 \times 3.06 = 76.5$ feet; and the power will be increased $(\frac{7}{4})^3 = 5.36$ times, to $2.53 \times 5.36 = 13.56$ h.p.

70. The actual capacity of the pump is also affected by certain conditions, principally by the friction losses of the liquid through the pump. Since these losses vary for different velocities, the capacity of a pump is not increased in exact proportion to the increase in velocity. Another condition that affects this relation is due to the design of the impeller and casing, particularly in the case of the so-called "non-overloading" impellers, which are designed with restricted inlet areas, so that with a predetermined absolute pressure at the inlet, they will not deliver more than some predetermined volume of water, no matter how much the head is decreased.

71. Velocity of Impeller.—As stated in Art. **68,** the theoretical velocity of the extreme outside points of the impeller is given by the formula,

$$v = 8.02\sqrt{h}$$

this formula gives the velocity in feet per second; hence, if the velocity v' in feet per minute is desired, the right-hand member of the equation must be multiplied by 60, the formula then becoming

$$v' = 481.2\sqrt{h} \qquad (1)$$

The velocity thus determined is that required to overcome the head; it does not provide for the velocity of flow through the discharge opening of the pump, which may be represented by v''. The velocity v'' depends only on the size of the discharge opening and on the volume of discharge, it has nothing to do with friction or other resistances. Therefore, the peripheral velocity v of the impeller is expressed by the formula,

$$v = 481.2\sqrt{h} + v'' \qquad (2)$$

Let G = the capacity of the pump in gallons per minute, d = diameter of discharge opening in inches, and v'' = velocity through discharge opening in feet per minute; then, the discharge in cubic feet per minute is

$$\frac{\pi d^2 v''}{4 \times 144} = \frac{231G}{1728};$$

from which,

$$v'' = 24.51\frac{G}{d^2}. \qquad (3)$$

Substituting this value of v'' in formula (2),

$$v = 481.2\sqrt{h} + 24.51\frac{G}{d^2}. \qquad (4)$$

Example.—A centrifugal pump is to discharge 925 gal. per minute against a head of 58 ft.; if the diameter of the discharge opening is 5 in., (*a*) what should be the peripheral speed of the impellers? (*b*) if the impellers are to make 1200 r.p.m., what should be their diameter?

Solution.—(*a*) Substituting in formula (4) the values of h, d, and G,

$$v = 481.2\sqrt{58} + 24.51 \times \frac{925}{5^2} = 4572 \text{ ft. per minute. Ans.}$$

(*b*) Let d' = the diameter in inches of the circle described by the outermost points of the impellers; then the circumference of this circle in feet is $\frac{\pi d'}{12}$, and this multiplied by the r.p.m. of the impeller must equal the peripheral speed. Hence,

$$\frac{\pi d'}{12} \times 1200 = 4572,$$

from which,

$$d' = \frac{45.72}{3.1416} = 14.553, \text{ say } 14\tfrac{9}{16} \text{ in. Ans.}$$

72. Velocities at Pump Inlets and Outlets.—To obtain efficient operation, the sizes of the inlet and outlet openings must be such that the liquid does not pass through them at too high a velocity; otherwise, the friction losses will be excessive, thus greatly

decreasing the effective head. For centrifugal pumps, the following range of velocities will meet the usual conditions:

At suction inlet, 6 to 12 feet per second;

at discharge outlet, 8 to 14 feet per second.

These velocities may be classified, according to sizes of pumps and the heads pumped against, as shown in the following table:

VELOCITIES AT INLET AND OUTLET (FT. PER SEC.)

	Head in feet				
	0–20	20–40	40 and up	60 and up	80 and up
		Small pumps (Up to 4 in. discharge)			
Inlet	6	10	10		
Outlet	8	12	12		
		Medium size (5–15 in. discharge)			
Inlet	7	8	9	10	
Outlet	9	10	11	12	
		Large pumps (18 in. and up discharge)			
Inlet	8	9	10	11	12
Outlet	10	11	12	13	14

The friction losses mentioned above vary directly as the area of the wetted surfaces of the metal over which the water passes, and as the area of cross section of the water passages. Since they also vary as the square of the velocity of the water through these passages, irrespective of the pressure of the water within the casing, it will at once be seen that the smaller pumps will have greater friction losses than the larger pumps for the same velocity. Consequently, since the friction loss for a given velocity remains constant regardless of any variation of head (pressure), by increasing the head, higher velocities may be handled without increasing the friction losses proportionately to the increase in head.

72*A*. Pump Efficiency Based on Capacity.—The table below represents good average efficiencies for pumping water, white

water, and light paper stocks (containing less than 1% fiber). These efficiencies are not the maximum obtainable at the present time for pumps that have been specially designed to obtain the maximum efficiency under given conditions. The values here given are based on enclosed type impellers; pumps with open type impellers will give efficiencies approximately 10% less.

Capacity, U. S. Gallons Per Minute	Pump Efficiency, Per Cent
100	55
150	60
225	63
350	68
600	73
900	76
1350	78
2400 and upwards	80

The tabulated values are based on pump efficiencies as related to capacities, and they do not allow for the changing maximum efficiency of a pump when the speed and head are changed. For capacities intermediate between those here given, values of efficiency sufficiently accurate for practical purposes may be obtained by ordinary interpolation. See *Mechanics and Hydraulics*, Vol. II, Art. **195**.

73. Stock Efficiency.—When pumping stock, the friction losses are greatly in excess of those that occur when pumping clear water. A prominent manufacturer of centrifugal pumps for pumping paper stock claims that the following chart, Fig. 26, will give accurate values for the loss in head and capacity when stock is being pumped. It is assumed, of course, that the pumps when in use are running at somewhere near their rated capacity. The values obtained from this chart may be applied to any well-designed centrifugal pump used for pumping stock. A considerable change in viscosity takes place during beating; factors or curves for this in terms of friction loss in pumping have not been worked out.

Let H = the actual horsepower of the pump when pumping clear water;
H' = actual horsepower of pump when pumping stock;
G = actual capacity in gallons per minute;
G' = equivalent stock capacity in gallons per minute;
h = the total lift or head in feet;

h' = equivalent head when pumping stock in feet;
η = efficiency of pump;
η' = efficiency of pump when pumping clear water;
η'' = stock efficiency of pump;

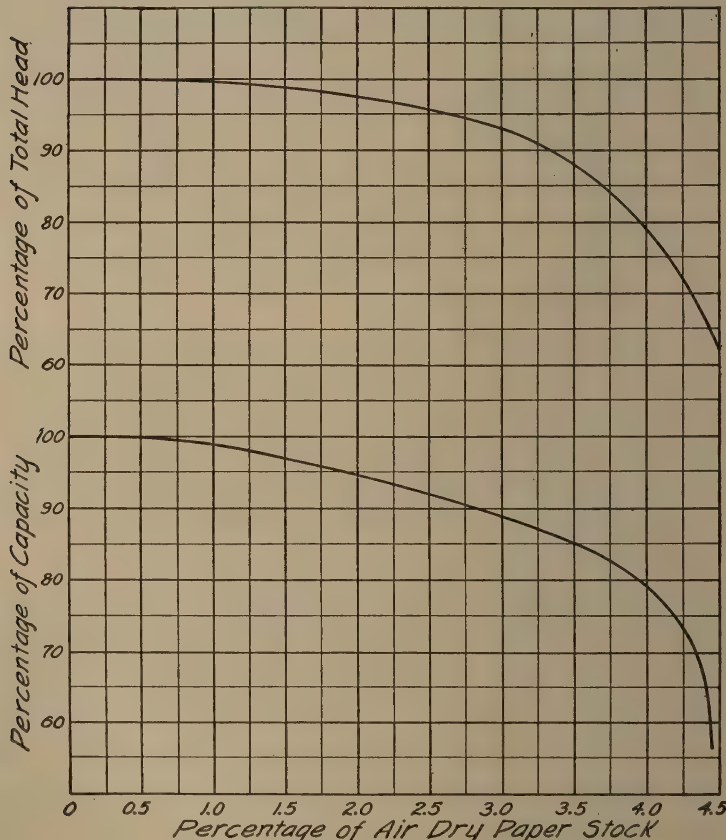

FIG. 26.

then, the **stock efficiency**, which may be defined as the ratio of the work done when pumping clear water to the work done when pumping stock, is

$$\eta'' = \frac{H}{H'} = \frac{hG}{h'G'} \qquad (1)$$

and the efficiency of the pump when pumping stock is

$$\eta = \eta'\eta'' \qquad (2)$$

The use of the chart in finding the values of G' and h' is best explained by means of an example. Suppose the pump is required to deliver 1200 gallons per minute of 3.5% stock, the total lift being 48 feet. Here $G = 1200$ and $h = 48$. For the same horsepower, the capacity when pumping stock will be less than when pumping water, and the head will also be less, and the chart gives the percentages of water capacity and head, from which the equivalent capacity and head may be obtained. Thus, referring to the chart, the bottom row gives the consistencies in per cent; following the vertical line that runs upwards from 3.5, it crosses the upper, or head, curve at about 88%, and crosses the lower, or capacity, curve at about 85%. The equivalent head h' is then equal to $48 \div 0.88 = 54.5$ feet; the equivalent capacity is $1200 \div 0.85 = 1412$ gallons per minute $= G'$; and $\eta'' = \dfrac{48 \times 1200}{54.5 \times 1412} = 0.748 = 74.8\%$.

If when pumping clear water, the efficiency of the pump is $\eta' = 65\%$, the efficiency of the pump when pumping stock under these conditions is

$$\eta = 0.65 \times 0.748 = 0.486 = 48.6\%. \quad \text{Ans.}$$

Note that the value of η'' may be obtained more easily by multiplying the two values obtained from the chart; thus,

$$0.88 \times 0.85 = 0.748 = 74.8\%.$$

The equivalent capacity does not mean that the pump will deliver that amount; it means that the horsepower required to operate the pump will be increased to the extent that corresponds to that capacity, and this also applies to the increase in head. The amount actually delivered by the above pump is 1200 gallons per minute, and the actual height of lift is 48 feet. The theoretical horsepower of the pump is

$$0.00025278 \times 48 \times 1200 = 14.56 \text{ h.p.}$$

while the actual horsepower is $14.56 \div 0.486 = 30$ h.p.

74. Pump Characteristics.—By the term **pump characteristics** is meant the information obtained by subjecting a pump to actual test under varying conditions of head and discharge, the speed remaining constant at some fixed number of revolutions per minute. When this information is plotted on a chart, the curves so obtained are called **characteristic curves.** The curves usually plotted are those for efficiency, horsepower, and head, the result being similar to the charts shown in Fig. 27.

There are two general types of pump characteristics, and both types are controlled by the pump designer; i.e., either type may be obtained by proper design of the pump. To obtain the characteristic curves shown in Figs. 27 to 27*c*, the pumps were all designed to operate under the normal conditions of a discharge of 1000 U. S. gallons per minute against a total head of 100 feet, and the same scale was used in each chart. The two general types of pump characteristics are called steep characteristic and flat characteristic.

The **steep characteristic** is so called because the total head changes quite rapidly, see Fig. 27, with changes in capacity.

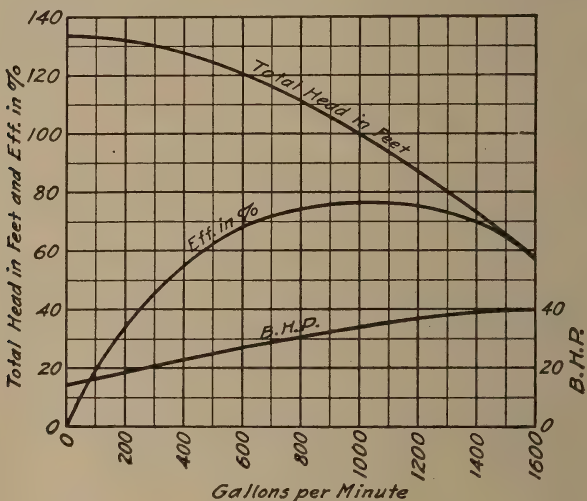

FIG. 27.

Note that the efficiency and discharge are both 0 when the total head is 133 feet; also, that the maximum discharge of 1600 gallons per minute occurs when the total head is 57 feet. This is not the point of maximum efficiency, however, which occurs for the normal discharge of 1000 gallon per minute, for which the pump was designed. Note that the changes shown by the characteristics are due to changes in head and discharge only, the speed of the pump remaining fixed at some predetermined number of revolutions per minute, in accordance with the definition in the first paragraph of this article.

The **flat characteristic**, see Fig. 27*a*, is thus called because the total head changes much less rapidly with changes in capacity

than is the case with the steep characteristic. Note that the efficiency and discharge are both 0 when the total head is 110 feet in this case; also, that the maximum discharge of 1600 gallons per minute occurs when the total head is 76 feet. The maximum efficiency is obtained when the discharge is 1200 gallons per minute, and there is but a slight falling off when the discharge reaches 1600 gallons per minute with a head of 100 feet and the rated discharge, the efficiency drops only 2% from the maximum. The chief difference in the design of these two pumps lies in the fact that, in the first case, the pump was given a higher peripheral impeller velocity and a lower outlet vane.

Both of these general types of pump characteristics have useful applications in pumping service. For example, the steep characteristic is more suitable where a greater head or pressure may be desired at capacities below normal; or where, due to the rapidly dropping head beyond the normal capacity, the danger of overloading the prime mover is reduced. On the other hand, the flat characteristic is selected when a wide range of capacity is desired with a minimum change in the pumping head or pressure when operating at constant speed, such as motor-driven boiler-feed pumps.

Another type of characteristic sometimes obtained is the so-called **drooping characteristic,** see Fig. 27*b*. This is so named because, after reaching a maximum head, the total-head curve drops from that point until the shut-off, or zero capacity, point is reached. Note that between the 0 capacity point and the corresponding total-head quantity (in this case, 720 gallons per minute at 115 feet head), the pump registers two entirely different capacities for each total-head point on this part of the curve. This rather peculiar performance is due to imperfect design, although pumps having such characteristics frequently show high efficiency at some point on their characteristic. Some pump manufacturers have found how to avoid this characteristic in their designs; they have even discarded such pumps entirely, regardless of any high efficiency they show at some point of the curve, since their operation is dangerous under some conditions of service, such as fire fighting or boiler feeding, when a pump may be operating at 0 capacity, or at a very much less capacity than the discharge pressure gauge would appear to indicate.

When two or more pumps discharge into the same piping system at the same time, they are said to be operated in parallel,

or they are in parallel operation. It is almost obvious that pumps operating in parallel should be designed for the same character-

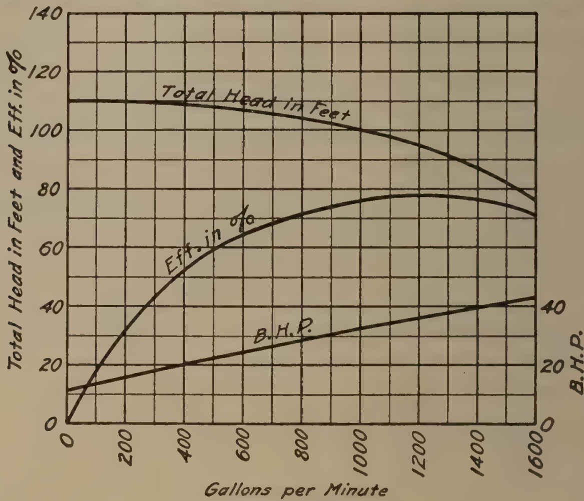

FIG. 27a.

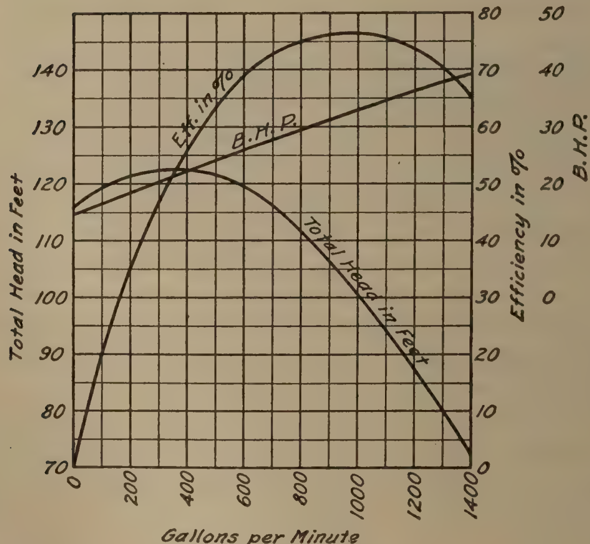

FIG. 27b.

istics, and that they should be installed so as to have the same static and friction heads, if possible. However this ideal condition is not always practicable; but a knowledge of the true

characteristics of each pump will indicate what may be expected from parallel operation. Fig. 27*c* shows the total-head curves of Fig. 27 and Fig. 27*a* plotted on the same chart; they cross each other at the point of normal capacity, 1000 gallons per minute and 100 feet total head. Assume, now, that the increased pipe friction due to parallel operation (greater discharge) increases the total head from 100 feet to 108 feet, for example; then, the pump with the flat curve will deliver for the 108-foot head, 590 gallons

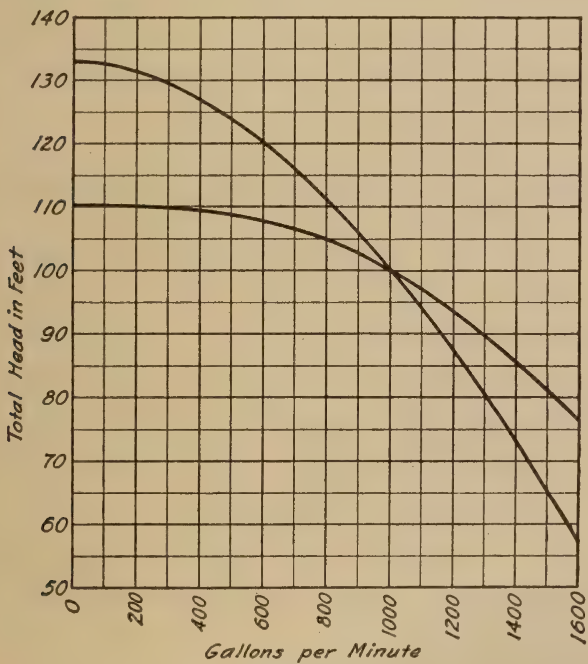

FIG. 27*c*.

per minute, and the pump with the steep curve will deliver 868 gallons per minute, and both together will deliver 590 + 865 = 1455 gallons per minute.

On the other hand, if, because of reduced static head or, perhaps, because of installation of larger pipes, the total head is reduced below 100 feet to, say, 80 feet, then the pump with the flat characteristic delivers 1530 gallons per minute, and the pump with the steep characteristic delivers 1310 gallons per minute, and both pumps deliver 1530 + 1310 = 2840 gallons per minute. It will be noticed that below the normal total-head

conditions, the two pumps change places in regard to their relative capacities.

Operating troubles may also be determined by checking actual results against the curves. Thus, if there be excess slippage due to internal wear, and the pump is operating at the speed for which the curves were drawn, both the head and capacity will be less than they should be for the horsepower consumed as compared with those indicated by the curve for the same conditions. Much other useful information can be obtained from these curves, such as checking the head against the discharge, the discharge against the head, what will happen if the location of the pump is changed, etc.

GENERAL INFORMATION CONCERNING PUMPS

SELECTION OF PUMPS

75. Pumping Groundwood Pulp.—Centrifugal pumps of the single-stage type are best suited to handling groundwood pulp; they may be either single suction with thrust bearings or double suction, provided, in the latter case, they are designed with large areas in the suction passages. Enclosed impellers have been used for handling pulp up to 3% air-dry stock; but for consistencies greater than 1 per cent of air-dry stock, open impellers are preferred on account of their higher commercial efficiency.

If the pulp contain more than 4.5% air-dry stock, use a pump of the plunger type, equipped with ball valves (or a rotary or specially designed centrifugal pump) because, on account of the thick material that is then handled, it must flow very slowly. In all these cases, whatever type of pump be used, there should be a gravity feed to the suction whenever possible. Pumps of standard cast-iron construction are well adapted to this service.

76. Pumping Sulphite Pulp.—The same types of pumps as recommended for groundwood pulp should be used for sulphite pulp, except that when centrifugal pumps are used, it is advisable to use open impellers in all cases. The pumps used for blow-pit service also come under this heading. Sulphite pulp is likely to be slightly acid; hence, the pump cylinders should be made of, or lined with acid-resisting metal.

77. Pumping Chemicals.—Centrifugal pumps, of single-stage, single- or double-suction type, with either open or enclosed impellers, may be used. The material of which the pump is constructed to resist the corrosive action of the chemical pumped will depend on the kind of liquid to be pumped. The following list will indicate the most suitable construction material for different liquids handled. It will be understood that the materials here listed, except cast iron, are used only for those parts of the pump that come into actual contact with the liquid pumped; the remainder of the pump may be of standard construction.

Liquid	Material
Acetic acid (diluted)	Enamel
Alkaline liquid (concentrated)	All iron
Alkaline liquid (diluted)	Enamel or all iron
Aluminum sulphate	Bronze fitted
Brine	Bronze fitted
Calcium acid sulphite (bisulphite liquor)	Bronze
Calcium hypochlorite	Enamel
Caustic soda	Cast iron
Caustic chloride of sodium	All iron
Cellulose	Plain fitted
Chloride of lime	Enameled
Chlorine in water	Enameled
Copperas (iron sulphate)	All iron
Fuel oil	Plain or bronze fitted
Glue	Bronze fitted
Lime water	All iron
Lye (caustic)	All iron
Lye (salty)	Bronze or brass fitted
Milk of lime (calcium hydrate)	All iron
Oil (all kinds)	Cast iron
Salt brine	Bronze fitted
Soda (sodium hydrate)	All iron
Soda ash (sodium carbonate)	All iron
Sodium chloride (common salt)	All bronze
Sodium sulphide	All iron
Sulpholignic salts (concentrated)	All bronze
Sulphonignic salts (diluted)	Bronze fitted
Sulphur dioxide	All bronze
Sulphurous acid (gaseous)	Bronze fitted
Sulphurous acid (diluted)	All bronze
Wood pulp	Bronze fitted

This list has been developed from actual experience in pumping the liquids named, as well as from the consideration of the

chemical reactions that may occur where the liquids pumped come into contact with the metals of which the pumps are made. The most suitable combination should be selected, both with regard to the durability of the pump and the effect on the material of the liquids handled. The selection of pumps for handling corrosive liquids should have these objects in view rather than the first cost of the pump.

78. Pumping Stock.—Pumps for handling heavy groundwood stock from 3% to 5% consistency, are usually of the open-impeller type of centrifugal pump, and of standard cast-iron construction. They should be so selected as to be of ample capacity, with large passages throughout the pump, thus permitting very moderate velocities in the liquid. A velocity of discharge of 5 to 6 feet per second will usually result in a more satisfactory and reliable operation than when higher velocities are used, and a uniform, constant flow through the pump will be maintained at a fair efficiency.

Pumps for handling light groundwood stock, up to 3% consistency, are also of the single-stage centrifugal type; they may be either single or double suction, with either open or enclosed impellers. A good general rule to follow is to install single-suction, open-impeller pumps for discharge openings up to 6 inches diameter; but for discharge openings greater than 6 inches, install double-suction pumps. Higher velocities of liquid through the pump may be used for light stock than for heavy stock, because, with light stock, a uniform flow can be maintained at these higher velocities, which may range from 8 to 12 feet per second through the discharge openings.

Pumps for handling white water should be of the single-stage centrifugal type, with either single or double suction and enclosed impellers. When pumping stock or white water, the pump should be so located that there will be a gravity flow to the suction inlet.

79. General Water Supply.—Pumps for handling the general water supply may be either of the centrifugal type (usually driven by a motor or a steam turbine) or else they are steam- or power-driven piston or plunger pumps. Centrifugal pumps are coming into more general use for this purpose, not only for manufacturing plants but also for towns and cities, on account of their adaptability for direct connection to high-speed electric motors and

steam turbines, and their high efficiency. For steam-driven units, a high-grade, reciprocating plunger pump, with triple-expansion steam end, will usually give a higher efficiency test than a centrifugal pump driven by a steam turbine, both being of the same capacity. However, considering the operating costs over a whole year, and taking into consideration the lower first cost, the smaller foundations and housing accommodations, and the lower cost for oil and attendance, the centrifugal-pump, steam-turbine unit will show a lower yearly cost for operation, interest, and depreciation.

It may here be stated that a centrifugal pump has recently been designed that is practically unchokeable; it will pass bolts, stones as large as the fist, etc.

80. Boiler Feeding.—For boiler feeding service, there are two standard types of pumps in general use, the direct-acting steam pump and the motor- or turbine-driven centrifugal pump; which type to use is generally fixed by the capacity of the boiler plant. The dividing line is determined by fixing the point where the greater efficiency of the more expensive type will show that it is an economical investment to spend more money on the original purchase, getting it back again by reason of more economical operation. The point where it is usually considered that these two types of pumps meet on an equal basis is the 2000 boiler horsepower plant. Roughly speaking, a **boiler horsepower** is equivalent to the evaporation of 35 pounds of water per hour; hence, a 2000 horsepower plant should evaporate $35 \times 2000 = 70,000$ pounds of water per hour, which is equivalent to $70,000 \times 0.12 \div 60 = 140$ gallons per minute. (One pound of water = 0.12 gallon.) For plants up to 2000 boiler horsepower, the direct-acting steam pump may be best; for larger units, the centrifugal pump is the more economical.

For boiler feeding service in smaller sized plants, the direct-acting steam pump is a very reliable and flexible unit. Being operated by steam pressure from the boilers to which feed water is being supplied, these pumps may be controlled by a pressure regulator, acting on the steam supply pipe to the feed pump. This operates automatically to maintain a constant water level in the boilers under all conditions of load, and to supply the proper amount of feed water, by compelling the pump to run at the proper speed. In the case of the centrifugal unit, there is

a decided advantage in that a sudden shut down of the boilers, or the closing of a valve in the supply line, will not build up the pressure beyond approximately 10% over the normal working pressure, and the pump may continue to run under such conditions for some time. It may here be remarked that practically all the larger power plants have adopted the centrifugal unit for boiler-feeding service. For the much higher boiler pressures that have recently been adopted, centrifugal boiler-feed pumps are used; they are operated at pressures up to 600 pounds per square inch.

A very important matter in the selection of boiler-feed pumps is the consideration of a positive head on the suction, and of its relation to the maximum temperature and the maximum capacity of the pump at that temperature (see Art. **66**).

PUMP OPERATION

81. Pump Troubles.—It may be safely asserted that more than one-half of all the operating troubles originate at the suction side of the pump, and this is particularly true of pumps having a suction lift.

Where a pump can be so located that the water or other liquid pumped can flow into the suction inlet under a gravity head, most of these suction troubles will be avoided; it is then only necessary to provide suction-pipe connections of such ample size that they will provide for a moderate flow and avoid high points, or air pockets, along the pipe line. Air pockets will accumulate air and retard the flow of the liquid. In the majority of pumping operations connected with pulp and paper mills, the gravity feed arrangement can be, and usually is, provided for; hence, these plants are usually comparatively free from suction-pipe troubles. In many cases, however, the suction pipes provided for handling heavy stock, particularly in blow-pit pumping, are too small in area to permit a sufficiently free flow into the suction inlet of the pump. For this kind of pumping, it is, therefore, recommended that the area of the suction opening of the pump, and of the entire suction or feed line between the pump and the tank or other source of supply, be approximately three times the area of the discharge opening; that is, if d be the diameter of the discharge opening, the diameter of the suction opening and feed-line pipe should be $d\sqrt{3} = 1.732d$. For instance, a pump having a dis-

charge outlet 6 inches in diameter, and used for pumping heavy stock, should have a suction inlet and feed-pipe line at least 10 inches ($1.732 \times 6 = 10.4$) in diameter; and if the pipe line is of considerable length, it will be well to make the diameter 12 inches.

Where a suction lift is necessary, it should be kept within the minimum limits allowable; it is less difficult to provide tight connections for a low suction lift than when a high vacuum is required for a high lift. In the latter case, a small leakage of air into the suction will expand into considerable volume; this will greatly reduce the flow of water into the pump, and it may, in some cases, entirely stop the flow.

In every case where a suction lift exists, it is necessary that all joints above the water level, between the supply and the pump, be made as tight as possible against air leakage into the pipe line. Any horizontal line of piping should be laid straight and level, or, preferably, with an incline upwards toward the pump; it should be free from high points, or air pockets, which collect air and retard or cut off the flow to the pump. This precaution is most important; but, although it seems to be quite generally understood as being essential to successful pump operation, yet there are numerous instances where it has not been observed, and the result is trouble, invariably.

Another important detail in connection with the suction pipe is that the lower end should be completely submerged in the water supply. This end should be carried well below the water level, to prevent the formation of eddy currents at the pipe entrance, since these fill with air; which may be drawn into the suction pipe when the end is not sufficiently below the surface of the water.

In cases where foot valves are used at the lower end of the suction pipe, or where check valves are installed in the suction line, care should be taken to select valves of such design as will permit an opening having an area that is at least equal to the area of the suction pipe. This is very important in connection with centrifugal installations, where the valve must remain open to permit a steady flow to the pump.

By far the greatest amount of trouble in connection with any type of valve pump is with the water valves; and this occurs in spite of an extraordinary degree of intelligent engineering skill, combined with practical ability, that has been brought to bear on the subject of the best designs and materials for obtaining the most satisfactory results. If the operating engineer having

pumps of this kind has his water valves in good working order, he has reduced his mechanical troubles to a minimum. Every pump operator should obtain as complete an understanding as is possible regarding the water-valve construction of his pumps, and regarding the type of valves best suited to his service conditions in the matter of durability, freedom from leakage, and smooth, quiet operation.

82. Spare Parts.—After the engineer has decided on the best kind of water valves to use in his pump, he should see that a few spare valves are kept on hand; not only the valves but also a few stems or valve bolts, springs (if used), and valve seats as well. It is not generally necessary to carry in stock a full set of valve parts, unless the pump be located where prompt delivery from the factory is impossible. Pump valves do not usually need renewal in complete sets, only one or two at one time; and if they are made of rubber composition, they will deteriorate when left exposed to the atmosphere, thus becoming practically useless. It is therefore considered best to carry a stock of about one-half the number of valves and valve parts that are required to equip the pump, and to order new ones as soon as any of these have been used.

83. Repairs.—Regardless of what precautions are taken to keep spare parts in stock, there may be times when these are not available; in such cases, temporary repairs may be made, which will keep the pump running until new parts are available.

When a pump is out of commission by reason of the breaking of one or more of the water-valve disks, these may be replaced for the time being by temporary disks, made of metal plates, when the pump has water valves of the standard flat-disk type. Or, if suitable material for making the temporary valves is not available, the valve opening may be blanked off with a disk of steel plate or wood. This last can be done only in the case of pumps having two or more valves at each corner, since it would not be possible, of course, to blank off an entire valve area and still operate the pump.

It may happen that the entire valve service, including the valve seat, may get loose, go out through the discharge pipe, and not be recovered; in such case, the entire valve seat opening may be blanked off as shown in Fig. 28, until a new valve seat can be fitted to the pump.

When valve seats that are screwed into place in the valve disks become loose, due to corrosion of the threads or to stripping, the thread in the valve disk should be re-tapped with an over-size tap, the new valve seats being threaded accordingly. When valve seats that are pressed into the valve deck in a bored taper become loose, the valve seat opening in the deck should be reamed out, and the new valve seats should be machined to fit the opening that has been reamed out.

In fitting new valve seats, it is essential that they are secured as tight as it is possible to make them, in order to keep them from working loose. The next most important detail is to have them square and true, so the seating surface is free and horizontal; and to have the valve bolts or stems vertical, so the valve may open and close freely and seat true and tight.

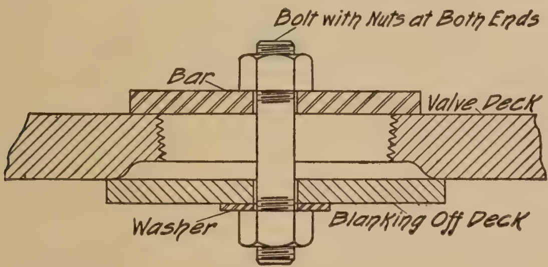

FIG. 28.

84. Starting the Pump.—In starting a reciprocating pump under pressure, it may fail because of full water pressure resting on the discharge valves; the air remaining in the pump cylinder is compressed, and this keeps the water from entering the cylinder. It is therefore advisable to have a by-pass between the suction and discharge chambers, with an intermediate globe or gate valve to prime the pump.

If, when starting a new pump, it does not operate smoothly, the first thought usually is that the steam valves are not properly set. These valves should be the last thing to be disturbed. There is only one proper position for the steam valves of a duplex pump, and they are placed in this position in the testing room of the factory before the pump is tested; any changes made in them by the operator will prove nearly always to be wrong.

Make certain that the suction and discharge connections, water valves, and everything connected with the water end is all right. If, on starting a new pump or one that has recently been packed,

it is found that one or, perhaps, both of the pistons do not make a full stroke, the cause can usually be located at the stuffing boxes; they are probably packed too tight. When stuffing boxes are properly packed, it is only necessary to draw lightly on the glands in order to prevent leakage through the stuffing boxes; this not only reduces the friction but it also makes a much smoother working pump.

When the water pistons are packed with fibrous packing, trouble sometimes arises from the swelling of the packing, which

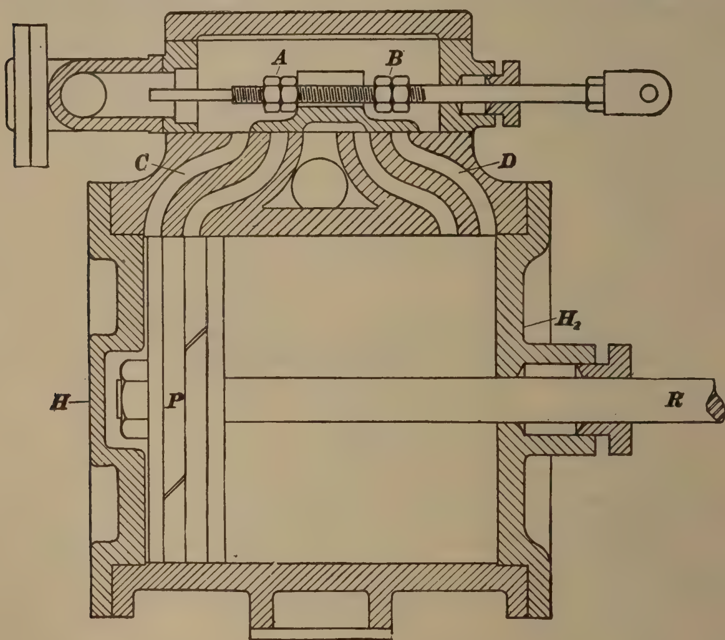

Fig. 29.

causes stiff, jerky, and uneven strokes; this is especially liable to happen when pumping hot liquids, and it is sometimes necessary to take out the packing and thin it down by stripping a layer from one side of the strand or ring, as the swelling is usually lateral. When providing a piston with new packing, it is well to soak the packing over night in warm water before fitting it in. New packing should fit the packing space loosely.

85. Setting Steam Valves.—Whenever it becomes necessary to reset the valves of a duplex pump, take off both valve-chest covers. Move piston rod *R*, Fig. 29, of the right-hand cylinder

until piston P strikes the cylinder head H_2. Adjust the nuts B on the valve rod so the steam port D is wide open. Then move the piston in the opposite direction until it strikes the other cylinder head H, and adjust nuts A so port C is wide open. In the same manner, adjust the valve of the left-hand cylinder. It is here assumed that the long lever is on the left-hand side of the pump, when standing at the steam end and looking toward the water end. Pumps that have only one adjusting nut, in the center of the slide valve, are adjusted in the same manner. Should it be found after adjusting the valve for port C and moving the piston to the oposite end of the cylinder, that the valve over-travels port D, adjust the valve so the travel is the same for both sides.

86. Centrifugal Pump Troubles.—The principal troubles encountered with centrifugal pumps are probably those due to improper priming or in not removing the air, which interferes with the operation of the pump. In cases where there is a possibility of trouble due to air pocketing in the pump casing, or in the suction pipe or fittings, if there should be a point that is higher than the inlet opening, the air should always be removed before starting the pump. If there is a head on the suction, the air cock on top of the pump casing should be opened until a full stream of water flows through it; as soon as this occurs, the cock should be closed and the pump started at once.

APPENDIX

TOTAL WORKING HEAD

87. Resistance Head in Pipes.—In *Mechanics and Hydraulics*, Part 4, Vol. II, the following formula was given for the flow of water through clean, smooth, cast-iron pipes:

$$v = 2.315\sqrt{\frac{hd}{fl + 0.1d}}. \qquad (1)$$

In this formula, v = velocity of flow in feet per second, h = the head in feet = difference of level between the entrance and exit plus any suction lift or minus any head on the suction; d = the diameter of the pipe in inches; l = total length of pipe in feet; and f = the coefficient of friction, which varies with the

velocity and is obtained from a table, which is here repeated for convenience.

COEFFICIENTS OF FRICTION FOR v IN FEET PER SECOND

$v =$ 0.1 $f =$ .0686	0.2 .0527	0.3 .0457	0.4 .0415	0.5 .0387	0.6 .0365	0.7 .0349	0.8 .0336	0.9 .0325
$v =$ 1.0 $f =$ .0315	1.2 .0300	1.4 .0289	1.6 .0280	1.8 .0272	2 .0265	3 .0243	4 .0230	5 .0221
$v =$ 6 $f =$ .0214	7 .0209	8 .0205	9 .0201	10 .0198	11 .0196	12 .0193	14 .0190	16 .0187

In the case of a pump, the velocity v is known or can be determined by the formula

$$v = \frac{0.4085G}{d^2}, \qquad (2)$$

in which G = the number of gallons discharged per minute, and d = the diameter of the discharge pipe in inches. The problem therefore becomes: to find the head necessary to overcome the resistances to flow (friction, etc.), the head required to give water its velocity of motion, and the static head (distance between the suction level and discharge level); the sum of these heads is the total working head of the pump, neglecting any resistance through the pump, which will be taken care of by the value of the efficiency of the pump. The first two of these heads are accounted for by h in formula (1); hence, solving formula (1) for h,

$$h = 0.1866v^2\left(f\frac{l}{d} + .1\right) \qquad (3)$$

88. Effect of Elbows, Tees, etc.—Formulas (1) and (3) of Art. **87** are applicable only to straight pipes of uniform cross section throughout. In the case of elbows and tees, which change the direction of flow, there is always a loss of head. If the branch pipes leading off the main are smaller than the main, there is an additional loss of head. However, for present purposes, only elbows and tees will be considered. There are several ways of estimating the loss from elbows and tees, and one or more authorities recommend that the length l in formula (3) be increased a certain amount for each elbow and tee; this amount is for

each elbow, 30 times the diameter of the pipe;
each tee, 60 times the diameter of the pipe.

EXAMPLE.—A pump is working against a static head of 36 ft., and is discharging 960 gal. of water per minute. The diameter of the discharge pipe is 7 in.; its total length is 725 ft.; and there are 21 elbows and 9 tees; what is the total head against which the pump works, assuming that there is no suction lift?

SOLUTION.—The additional length of pipe to be allowed for the tees and elbows is $(21 \times 30 \times 7 + 9 \times 60 \times 7) \div 12 = 682.5$ ft., thus making the value of l, to be substituted in formula (3), $725 + 682 = 1407$ ft. The velocity of flow is $\frac{0.4085 \times 960}{7^2} = 8$ ft. per second. The value of f as given in the table, corresponding to $v = 8$, is 0.0205. Now applying formula (3),

$$h = 0.1866 \times 8^2(0.0205 \times \frac{1407}{7} + .1) = 50.4+ \text{ ft.}$$

The total head against which the pump works is, therefore, $36 + 50.4 = 86.4$ ft. Ans.

If it be assumed that the pump in the above example has an efficiency of $66\frac{2}{3}\%$ $(= \frac{2}{3})$, the horsepower of the pump will be, using formula (4), Art. **61**,

$$H = 0.00025278 \times 86.4 \times 960 \times \frac{3}{2} = 31.33 \text{ h.p.}$$

The theoretical horsepower is

$$H = 0.00025278 \times 36 \times 960 = 13.1 \text{ h.p.}$$

Consequently, the efficiency of the entire combination is $13.1 \div 31.33 = 0.418 = 41.8\%$.

If the pump have a suction lift, and there is a 90° bend in the suction pipe at the inlet, the resistance head through the suction pipe must be calculated also, allowing an additional length of 10 diameters for the bend. For instance, suppose the static head were the same as before, 36 ft.; that the total length of the suction pipe was 22 ft., its diameter 8 in., and that it had a 90° bend at the inlet. The additional length on account of the bend would be $\frac{10 \times 8}{12} = 6.7$ ft., and the total equivalent length is $22 + 6.7 = 28.7$ ft. The velocity of flow through this pipe is, assuming a volumetric efficiency of 95%,

$$v = \frac{0.4085 \times 960}{8^2 \times 0.95} = 6.45 \text{ ft. per second}$$

From the table of Art. **87**, interpolating the value of f for $v = 6.45$, $f = 0.0212$, to 4 decimal places. Now applying formula (3), Art. **87**,

$$h = 0.1866 \times 6.45^2\left(0.0212 \times \frac{28.7}{8} + .1\right) = 1.4 \text{ ft.}$$

Assuming the other conditions to have remained the same, the total head against which the pump works is $86.4 + 1.4 = 87.8$ ft.

89. Velocity Head.—Strictly speaking, the result last obtained is not quite correct because formula (3) of Art. **87** includes the **velocity head,** which is the head required to give the water its velocity of flow through the pipe. This head has been counted twice—once for the discharge and once for the suction. But the velocity through the suction persists into the discharge; hence, only the head required to give the additional velocity of discharge, or $8 - 6.45 = 1.55$ ft. per second should be added to the velocity head on the suction.

It was shown in *Mechanics and Hydraulics*, Part 3, Vol. II, that height h (head) required to produce a velocity v is $h = \frac{v^2}{2g} = 0.01555v^2$. For a velocity of 6.45 ft. per sec., $h = 0.01555 \times 6.45^2 = 0.65 -$ ft.; hence, the total head against which the pump in Art. **88** works is $87.8 - 0.6 = 87.2$ ft. The difference is so small that it may well be neglected, particularly when it is considered that the values obtained by means of any formula for the flow of water through pipes are approximations only. Even with the highest practicable velocity of flow, say about 14 feet per second, the velocity head is only $0.01555 \times 14^2 = 3$ feet, and this velocity is seldom reached.

90. Influence of Consistency.—As might be inferred from the last paragraph of Art. **63,** the resistance head is greatly increased as the consistency of the stock increases. The flow of stock in pipes bears no simple relation to the flow of water, volume for volume. About all the information available bearing on this subject is based on a series of extensive and exhaustive tests made in 1907 by W. J. Trimbey, at the Glens Falls plant of the International Paper Co. The four charts here given are printed by permission of Mr. Philip T. Dodge, President International Paper Co., to whom thanks are extended by the Textbook Committee.

The pipe used in the experiments was spiral-riveted, galvanized-iron pipe, the stock flowing with the lap, and the pipe being laid horizontally. Both groundwood and sulphite stock was used, with practically the same result from each; so most of the runs were conducted on groundwood stock, and all runs were double-checked at later dates.

The loss of head varies not only with the velocity but also with the diameter of the pipe for the same velocity. The charts, Figs. 30 to 33, give the loss of head per hundred feet of straight pipe for different velocities and consistencies, for 6-, 8-, 10-, and 12-inch pipe; for intermediate sizes of pipe, sufficiently accurate values may be obtained for practical purposes by interpolation. Probably, also, sufficiently exact values for 13 and 14-inch pipe may be obtained by extrapolation; but it would not be advisable

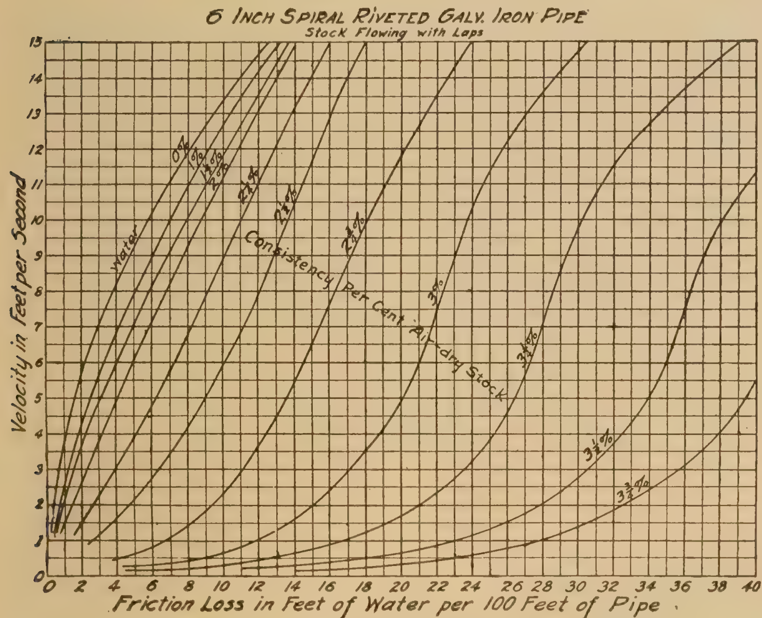

FIG. 30.

to use extrapolation for pipes smaller than 6 inches or larger than 14 inches.

The values obtained from these charts are probably somewhat greater than would be found for smooth cast-iron pipes, but the difference is not likely to amount to much; and since it is better to be on the safe side, these values may also be used for cast-iron pipes. Bends, elbows, and tees will, no doubt, exercise greater influence on the flow of stock than on the flow of water. However, in the absence of any information regarding their effects, they may be figured in the same manner as in the case of water,

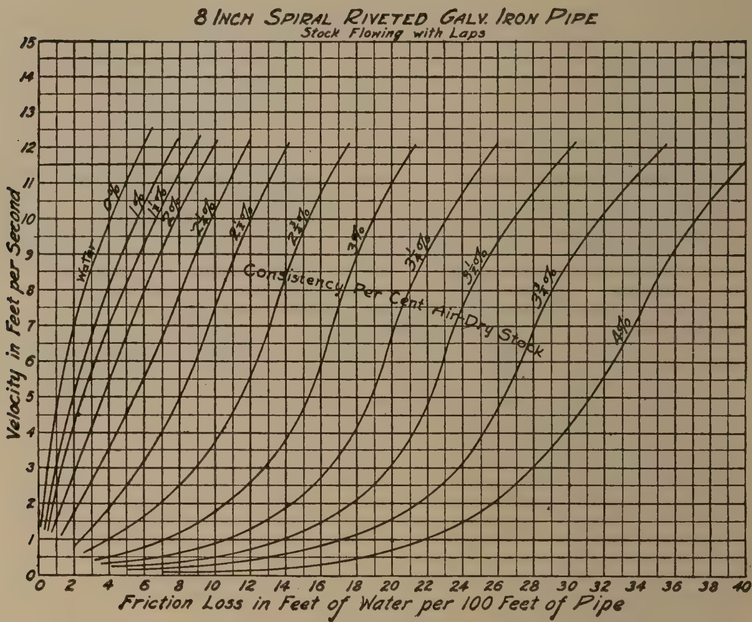
8 INCH SPIRAL RIVETED GALV. IRON PIPE
Stock Flowing with Laps
Velocity in Feet per Second
Friction Loss in Feet of Water per 100 Feet of Pipe
Consistency Per Cent Air-Dry Stock
Water
4%

FIG. 31.

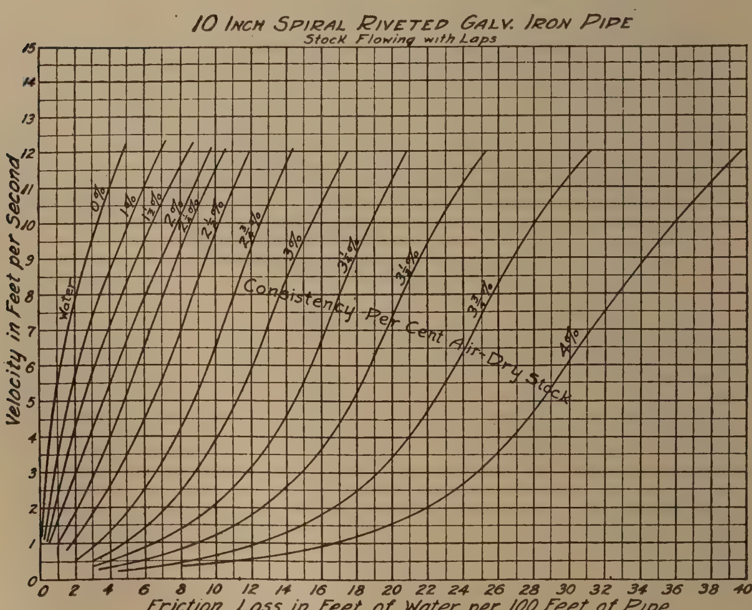
10 INCH SPIRAL RIVETED GALV. IRON PIPE
Stock Flowing with Laps
Velocity in Feet per Second
Friction Loss in Feet of Water per 100 Feet of Pipe
Consistency Per Cent Air-Dry Stock
Water
4%

FIG. 32.

by increasing the length of the pipe 10 diameters for 90° bends, 30 diameters for elbows and 60 diameters for tees.

EXAMPLE.—Referring to the example of Art. **88**, suppose stock of 3% consistency were being pumped, the other conditions remaining the same; what would be the total head pumped against?

SOLUTION.—It was found that the equivalent length of the pipe was 1407 feet and that the velocity was 8 ft. per second. Since the diameter of the discharge pipe is 7 in., find the loss of head for a 6-in. pipe and for an 8-in. pipe; add the two results and divide by 2; the quotient will be the

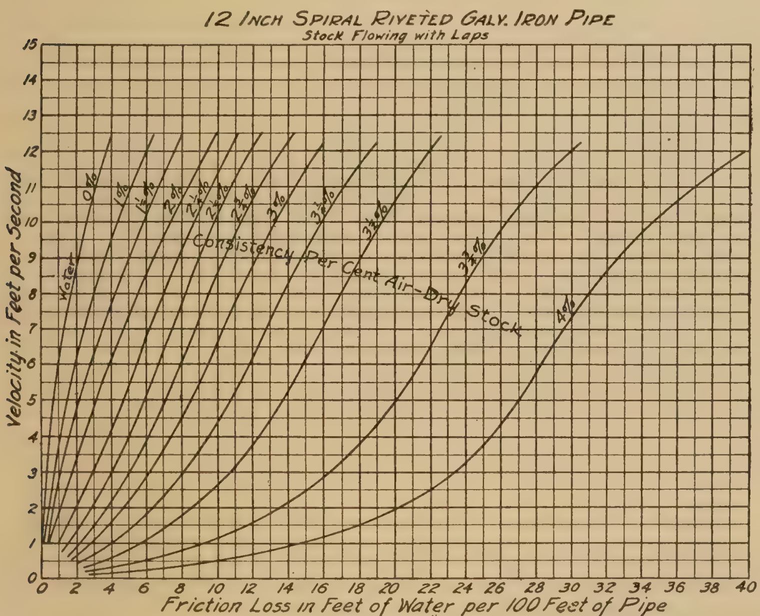

FIG. 33.

probable loss of head for a 7-in. pipe. From Fig. 30, the horizontal line through 8 in the left-hand margin intersects the curve marked 3% at the point where the vertical through 22.4 intersects the curve at the same point; hence, the loss of head for a 6-in. pipe, when the velocity is 8 ft. per second and the consistency 3%, is 22.4 ft. per hundred feet of pipe. Similarly, referring to Fig. 31, the loss of head per hundred feet of pipe for an 8-in. pipe, when the velocity is 8 ft. per sec. and the consistency 3%, is 17.4 ft. It is therefore assumed that the loss of head under the same conditions for a 7-in. pipe is $(22.4 + 17.4) \div 2 = 19.9$ ft. The entire loss of head is $19.9 \times \frac{1407}{100} = 280$ ft. Since the static head is 36 ft., the total head against which the pump works is $280 + 36 = 316$ ft. Ans.

Since the loss of head when pumping water was 50.4 feet, and was 280 feet when pumping stock of 3% consistency, the latter is $280 \div 50.4 = 5\frac{5}{9}$ times as great as the former.

91. Extrapolating Values for 13- and 14-inch Pipe.—Extrapolation is the process of finding values of functions for arguments beyond the limits of those in the table. In the present case, this process may be applied, perhaps without material loss of accuracy to finding loss of head for 13- and 14-inch pipes in the following manner: Find the desired value for an 11-inch pipe in the manner just described for a 7-inch pipe; find the difference between this value and the value for a 12-inch pipe; subtract this difference from the value for the 12-inch pipe, and the remainder is the value for the 13-inch pipe; subtract the same difference from the latter value, and the remainder is the value for the 14-inch pipe. The two values thus obtained will probably be a little larger than the actual values, but they will, no doubt, be close enough for practical purposes. Thus, suppose it be desired to find the loss of head for a 14-inch pipe when the velocity is 10 feet per second and the consistency is 3.5%. The corresponding values for 10- and 12-inch pipes are 22.6 and 19.3 feet, respectively; for an 11-inch pipe, it is $(22.6 + 19.3) \div 2 = 20.95$, say 21.0 feet; $21 - 19.3 = 1.7$. Then, the probable value for a 13-inch pipe is $19.4 - 1.7 = 17.7$ feet; and for a 14-inch pipe it is $17.7 - 1.7 = 26.0$ feet per hundred feet of pipe.

92. Effect of Higher Consistencies.—The present tendency is toward pumping at higher consistencies. Formerly, 4% stock was considered to be the practical limit; now, however, under suitable conditions of installation, stock up to 8% consistency is successfully handled. In Fig. 33*a*, is shown a characteristic friction curve. This was developed from tests made by Mr. Trimbey, at the Glens Falls plant of the International Paper Co., in 1907, and is represented by Fig. 32. The figures used for the development of Fig. 33*a* are from a test made by pumping stock through 10-inch, spiral-riveted, galvanized-iron pipe, the stock flowing with the laps. The moderate velocity of 5 feet per second was assumed, and the friction loss for different consistencies is read in feet of head per 100 feet of pipe line.

According to the best available information relating to stock friction, the tremendous pipe-line losses when handling the higher consistencies at even moderate velocities will add greatly

to the total pumping head, and hence to the power consumption; consequently, except for short, direct pipe lines, somewhat lower consistencies are generally advisable. In fact, experiments indicate that if pumping be conducted with stocks of increasingly higher consistencies, a critical point will soon be reached, beyond which a centrifugal pump would not deliver stock through the pipe line, regardless of its area.

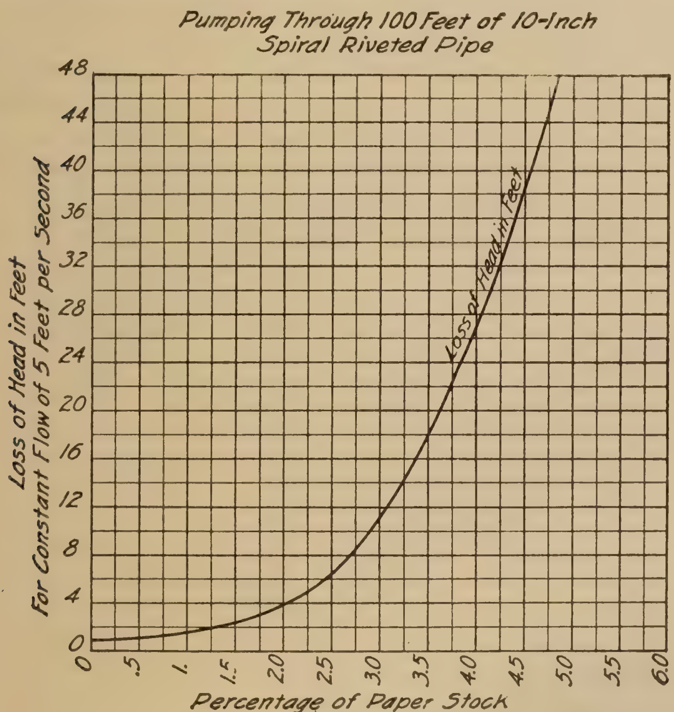

FIG. 33*a*.

An example of service where high-consistency stock may be handled advantageously is in the circulating agitators for mixing, when stock up to 8% consistency may be pumped economically, provided there is ample positive head on the pump inlet.

By studying Fig. 33*b*, a proper understanding of the relation between stock and water performance will be obtained. The water curve is developed to show full rated capacity at 100% rated head. When pumping 4% stock, the pump handles 83% rated capacity at 100% rated head; and 100% rated capac-

ity at 77% rated head. This stock-pumping performance represents a loss of 17% capacity at full rated head, or a loss of 23% of head at rated capacity. It will generally be found that the power curve for stock pumping will be almost identical with that shown for the water characteristic; consequently, the efficiency for stock pumping will be less than for water pumping. For example, if the water efficiency at 100% normal capacity is 70%, then, when pumping 4% stock, the efficiency will be 77 × 0.70 = 53.9%, due to loss of head in the pump when handling 4% stock. This loss of head may not be entirely attributable to the pump, though some of it is always caused by increased friction in the pump passages. In some cases, the difference in head

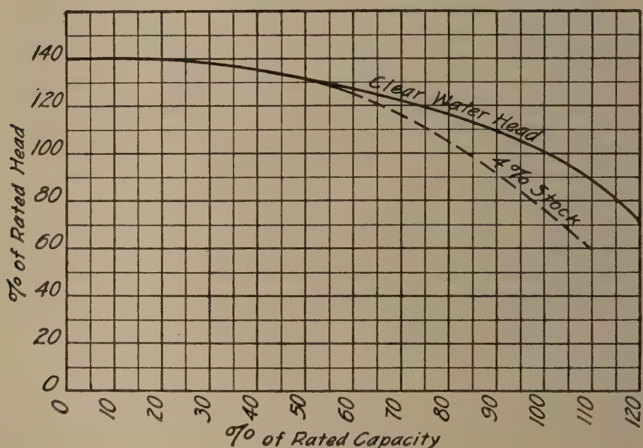

Fig. 33*b*.

between water and stock performance may be decreased by adding more positive head on the pump inlet, thereby gaining in net total pumping head.

It should be clearly understood, when estimating the hydraulic losses in the pump that must be compensated for in determining the speed and power for a given pumping condition, that such correction is based on a function of the capacity and stock consistency, and not on the head against which the pump operates, because these internal losses due to stock pumping will be indentical for the same capacity and consistency, regardless of what the pumping head may be.

92A. There are two elements controlling the performance of the stock-handling pump that are not ordinarily considered in the

case of pumps handling cold water: the loss of head due to internal friction in the pump; and the condition obtaining at the pump inlet. It is, perhaps, more or less well known that pumps will handle cold stock of low consistency under more or less suction-lift conditions; but when pumping stock of high consistency, the stock must always flow to the pump inlet under a positive head. The reason for this is that the limit of natural force available for feeding the stock into the pump is the surrounding atmospheric pressure; and the limit of pumping capacity is reached for any given inlet condition when zero pressure at the inlet is recorded.

When the limit of pump capacity is reached for any given inlet condition, ample evidence of this is usually furnished by a loud rattling noise inside the pump, which is caused by the forming of a partial vacuum at the inlet vanes, and the shock caused by alternate separation and recombination of the fluid entering the impeller by interruption of steady inlet flow, creating the unstable operating conditions. When this stage is reached, no amount of speed increase or reduction of the discharge head will increase the capacity, or stabilize operation, which can be effected only by increasing the head on the pump inlet, by reducing the consistency of the stock, or by installing another pump that is designed to operate with less head on its inlet.

92B. Centrifugal pumps used for stock pumping are of two general types—single suction and double suction. These are again subdivided, as regards impeller construction, into open and closed impeller types. The advantage of the single-suction pump lies in its short and direct inlet passage between the inlet flange and the impeller, which is desirable when handling extremely heavy stock. The disadvantages consist of the necessity for a thrust bearing or thrust-balancing device, which is often a source of trouble and a cause for shut down for repairs. The balancing holes may become partially or wholly obstructed with stock, which may interfere with proper balance: greater load is imposed on the thrust bearing during such a period.

The advantages of the double-suction pump lie in precisely those features that counteract the disadvantages of the single-suction pump; in addition, for low and moderate heads, an elaborate thrust bearing may be dispensed with entirely, and any slight momentary unbalanced condition may be relieved by

simple collars, attached to the shaft and located within the guide-bearing housings.

Open impellers are installed in either single- or double-suction pumps. Their advantages are that they are most effective in handling heavy stock or stock that is not uniform in consistency, and when a not unreasonable amount of short strings, ropes, etc. must pass through the pump. Their disadvantage lies in lower efficiency, which is principally due to side slippage between the impeller and casing; this tends to increase the wear and further to reduce the efficiency. A comparatively new development in double-suction open-impeller pumps has featured the designs of several pump manufacturers, who equip them with adjustable plates inside the casing and opposite both sides of the impeller vanes. They may be closed in to compensate wear, and the efficiency thereby returned to approximately that of a new pump (see Fig. 22*a*).

Enclosed impellers may be installed to best advantage under all those conditions not especially advocated for the open-impeller type. They give higher efficiencies than the latter, since slippage can be reduced to a minimum, and more effective velocities can be obtained through the impeller.

92C. Selection of Stock Pumps.—The selection of suitable stock pumps should be considered from several different angles, conditions that do not enter seriously into the average water pumping installation. The main points to be considered are:

(1) Maximum consistency of stock to be pumped.

(2) Maximum capacity of stock to be pumped at maximum consistency.

(3) Frictional resistance through the pipe lines, available or to be installed, considered in connection with total pumping head.

(4) Consideration of conditions at inlet of pump, and provision for suitable positive head, if necessary, or limitation of total suction lift in some cases.

(5) Type of pump and impeller best suited to the conditions; also its efficiency, normal characteristics, and speed.

(6) Power rating and speed required in suitable prime mover to cover the operating cycle under suitable loading conditions.

As a general rule, it may be stated that suction-lift operation of stock pumps may be undertaken when handling stock not

exceeding 3% maximum consistency under favorable conditions at the pump inlet, when the static lift is low; and when pipes are large, short, and direct. It is advisable to equip stock pumps with suitable handholes having easily removable cover plates. These handholes should be of ample size, and be conveniently located to give access to the interior of the pump, in case of interrupted service caused by an obstruction.

92D. Specific Weight of Stock.—It is customary to take the weight of a cubic foot of stock of any consistency as 62.5 pounds, or the same as that of water. This is practically correct, because even though the specific gravity of bone-dry fiber be 1.54, as applied to the substance making up the fibers, the fibers themselves are hollow, the volume of the hole being about one-third the volume of the fiber. Consequently, when the fibers are mixed with water, the specific weight of the mixture is practically unchanged. It is possible that drastic treatment in the beaters and Jordans might crush the fibers to such an extent as to increase the specific weight very slightly, but this would not materially alter the head.

GENERAL MILL EQUIPMENT

(PART 1)

EXAMINATION QUESTIONS

(1) (*a*) For what purposes are pumps used in the pulp and paper industry? (*b*) Why is a good knowledge of pumps and pumping essential to pulp and paper mill operators?

(2) What is (*a*) a simple duplex pump? (*b*) a tandem-compound duplex pump? (*c*) a triplex power pump?

(3) What is (*a*) an inside-packed pump? (*b*) an outside-packed pump? (*c*) a center-packed pump?

(4) (*a*) What is the principal difference between a piston pump and a plunger pump? (*b*) For what kind of work are plunger pumps best adapted, and why?

(5) Using your own wording, compare the single pump with the duplex pump; state which type you would purchase for general mill pumping, and why.

(6) If the diameter of a direct-acting steam pump is 12 in. and the steam pressure is 115 lb. per sq. in., what should be the diameter of the water plunger when the total head against which the pump works is 575 ft.? Ans. $8\frac{1}{8}$ in., say 8 in.

(7) (*a*) Mention some of the advantages of power pumps. (*b*) If a power pump is to make 56 r.p.m. and is to be driven from a motor that makes 1240 r.p.m., what arrangement of gear reduction would you use? (*c*) If the smallest gear had 18 teeth, how many teeth should there be in the other gears?

Ans. (*c*) 21, 90, and 93 teeth.

(8) (*a*) How does a rotary pump differ in its action from a centrifugal pump? Mention some of the uses to which rotary pumps are best adapted.

(9) (*a*) Explain the principle of action of a centrifugal pump. (*b*) What are diffusion vanes? (*c*) State the conditions under which diffusion vanes increase the efficiency of a pump.

(10) (*a*) Why is it necessary to prime a centrifugal pump? (*b*) Is it ever necessary to prime a rotary pump? why?

(11) What is (*a*) a turbine pump? (*b*) a multistage pump? (*c*) What is the difference between a turbine pump and a centrifugal pump?

(12) (*a*) In the case of a centrifugal pump, what causes end thrust? How may end thrust be avoided or counteracted? (*c*) Mention several ways of taking care of end thrust.

(13) What is the rated capacity in (*a*) gallons per minute, and (*b*) in cubic feet per minute of a single-acting triplex pump making 60 r.p.m., the diameter of the cylinder being 8 in. and the stroke 10 in.?

Ans. $\begin{cases} (a)\ 391.7 \text{ gal. per min.} \\ (b)\ 52.36 \text{ cu. ft. per min.} \end{cases}$

(14) What is meant by (*a*) volumetric efficiency? (*b*) slip? (*c*) If the volumetric efficiency of the pump in question (13) is 94%, what is the actual capacity of the pump?

Ans. (*c*) 368.2 gal. per min.

(15) A single-acting triplex pump having a diameter of 10 in. and stroke of 12 in., is making 42 r.p.m. If the total head is 75 ft., what is the probable horsepower required to operate this pump? Ans. 13.92 h.p.

(16) (*a*) What effect is produced on the suction lift by an increase in the temperature of the water? Referring to the chart, Fig. 25, what will be (*b*) the practical suction lift, (*c*) the maximum suction lift under the best conditions, and (*d*) the theoretical suction lift, when the temperature of the water is 85°?

(17) (*a*) What influence has the altitude of the pump above sea level on the suction lift, and why? (*b*) If the pump were situated below sea level, what effect would be produced on the suction lift? (*c*) If the pump were situated 1400 ft. above sea level, what would be the practical suction lift, the temperature of the water being 60°F.?

(18) What effect (theoretically) will be produced on (*a*) the head, (*b*) the capacity, and (*c*) the horsepower of a centrifugal pump by increasing its speed from 950 r.p.m. to 1300 r.p.m.? How are these effects modified in actual operation?

(19) A centrifugal pump is delivering stock of 3% consistency at the rate of 1100 gal. per min. The total working head, which includes all pipe resistances, is 195 ft. What is (*a*) the stock efficiency? The efficiency of the pump when pumping water is

72%; what is (*b*) the efficiency of the pump? What is (*c*) the actual horsepower of the pump?

Ans. (*a*) 81.8%
(*b*) 58.9%
(*c*) 92.1 h.p.

(20) (*a*) Where are pump troubles most likely to occur? (*b*) What special precautions should be observed in connection with the suction pipe?

(21) (*a*) What is a boiler horsepower? (*b*) About how many gallons of water per minute should be evaporated by a plant that is rated at 3200 boiler horsepower? (*c*) What type of pump would it be best to adopt to feed these boilers, and why?

Ans. (*b*) 224 gal. per min.

(22) A pump is delivering $2\frac{3}{4}$% stock at the rate of 1250 gal. per min. against a static head of 48 ft. If the diameter of the pipe is 8 in., the total length is 910 ft., and it has 1 90° bend, 15 elbows, and 8 tees, what is (*a*) the resistance head? (*b*) the total head against which the pump works? (*c*) If the efficiency of the pump is 62.5%, what horsepower will be required to operate it?

Ans. (*a*) 212.1 ft.
(*b*) 260.1 ft.
(*c*) 131.5 h.p.

SECTION 6

GENERAL MILL EQUIPMENT

(PART 2)

By H. E. Stafford and S. H. P. Wolferstan

CARE AND MAINTENANCE OF ELECTRICAL EQUIPMENT

INTRODUCTION

93. Kilowatts and Kilovolt-Amperes.—In *Elements of Electricity*, Part 2 (Vol. II, Sec. 2), it was shown that in the case of an alternating-current (or motor), the real power could not be measured by multiplying the e.m.f. (in volts) across the terminals of a circuit by the current in amperes through the circuit, except and only when the e.m.f. and the current are in phase with each other. In the case of a direct current, the voltage (e.m.f.) and the current are always in phase; hence, if P = the power in watts, I = the current in amperes, and E = the voltage in volts, $P = IE$, always. Dividing this product by 1000, the result is the power in kilowatts, which will hereafter be abbreviated to kw. when convenience is desired.

Consequently, if it were desired to measure the power of a direct-current generator, voltmeters would be placed at the terminals, across the circuit; at the same time, an ammeter placed at some convenient place in the circuit would also be read; then the two readings multiplied together would be the power output in watts of the generator at the instant the readings were taken. The same procedure would be taken to find the power input of a direct-current motor.

If, however, this method were applied to an alternating-current generator or motor, the result obtained would be called

the **apparent power**—it would not be the true power unless the e.m.f. and the current were in phase with each other, which is usually not the case on an alternating-current circuit—in general, the power will be less than the product I times E. For this reason, instead of expressing the apparent power of an alternating-current generator or motor in kilowatts, it is customary to express it in **kilovolt-amperes,** 1 kva. (kilovolt-ampere) being equal to the product IE divided by 1000 for single-phase circuits, and $\sqrt{3}IE$, divided by 1000 for three-phase circuits.

94. Mathematically, 1 kw. and 1 kva. are equal, but as expressing the power of a machine, they are not synonymous, 1 kva. representing less effective power than 1 kw., except in the special case when the voltage and current are in phase. The following explanation will make this clear.

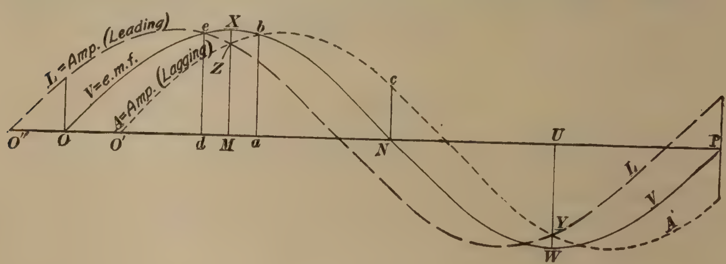

FIG. 34.

The diagram, Fig. 34, shows three curves, the one marked V and starting at O representing the variation in e.m.f. for one complete cycle (revolution) between O and P. This curve has been drawn in the same manner as that in Fig. 60 of *Elements of Electricity*, Sec. 2, Vol. II. Measurements taken horizontally (as along the line OQ) represent time, the distance OP being 360 degrees, the time of one complete cycle (the time it takes the field to pass a north pole and a south pole); measurements taken vertically, as MX, represent the e.m.f. at the instant of time indicated by OM. All vertical measurements taken *above* OQ are positive, and those below it are negative. The maximum positive voltage is at X, which is vertically over M, midway between O and N, and 90 degrees from O; the maximum negative voltage is at W, vertically under U, midway between N and P, and 270 degrees from O. The voltage is 0 at O, N, and P, the points where the curve crosses the line OP.

In an alternating current, the curve for the current follows the same law as that for the e.m.f., and the variation in current may be represented by the same kind of curve as that just mentioned; in fact, if the maximum current in amperes has the same numerical value as the maximum e.m.f., the same curve could be used to represent both the voltage and the current, provided they were in phase, and the product $I \times E$ would be the power in both watts and volt-amperes for single-phase circuits. When they are not in phase, however, the current is either **lagging** or **leading**; that is, the minimum value (which is 0) occurs *after* or *before* 0 value of the e.m.f. In Fig. 34, the dotted curve A represents a current whose maximum value is the same numerically as the maximum value of the e.m.f. of curve V, but its minimum value starts at $O,'$ say 30 degrees to the right from O; hence, curve A is a lagging current. This is the condition (a lagging current) that exists in nearly all commercial alternating-current circuits.

The power at any instant in *watts* may be found by drawing a vertical line at the point representing the time, as XY through the point M, and measuring the distances of M from curve V and A; the product of these distances, $MX \times MZ$, is the power in watts at that instant. The commercial measurement of power is obtained by using an integrating wattmeter, which records a summation of all these instantaneous products.

The greatest power, *i.e.*, maximum power, occurs where the two curves V and A intersect; this is at b, and the power here is $ab \times ab$. At N, the e.m.f. = 0; hence, the power is $Nc \times 0 = 0$. Observe that at N, the voltage curve V has completed a half-cycle, or 180 degrees. Had the two curves been in phase, both starting at 0, the maximum power would have been at point M, 90 degrees from O, and its maximum value would have been $MX \times MX$, which, as will be seen, is greater than when the current starts at $0'$, and is $ab \times ab$. The latter, the *real power*, is in watts, while the former, the *apparent power, which is always assumed in measuring an alternating current*, is in volt-amperes. It should now be clear why the volt-ampere is not a correct measure of the effective power of an alternating current; it is almost invariably greater numerically than the real power in watts, which is the power that actually does useful work.

If the current *leads* the voltage, or e.m.f., exactly the same results in relation to the numerical values of the power in watts

and volt-amperes will be obtained. This fact is illustrated by the curve L in Fig. 34, which is the current curve when it starts at O'', 30 degrees to the left (ahead) of O. The maximum power in this case is given by the product $de \times de$, which is exactly equal to the product $ab \times ab$, the only difference being in the times when the power becomes a maximum.

The fundamental law, applicable to all circuits, both direct and alternating current, is that *the power in watts at any instant is equal to the product of the instantaneous values of the voltage and current.*

The reason for using the term kilovolt-ampere is that it is necessary to have some definite unit to designate the apparent power of a circuit or some piece of apparatus, such as a generator or transformer, without considering or even knowing the condi-

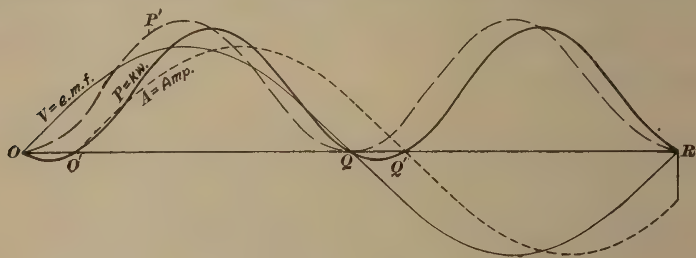

FIG. 35.

tions under which it is to work; consequently, the power of this apparatus is expressed in kilovolts, and the purchaser knows that if his machine has a power factor of 1, its power will be the same number of kilowatts. It is not feasible to refer to the power in kilowatts in these cases, because the conditions under which the apparatus is going to be used are not known.

It is interesting to note the effect produced on the power by a lagging (or leading) current. This is well illustrated in Fig. 35, in which curves V and A are the e.m.f. and current, respectively, and correspond in every respect with the same curves in Fig. 34. Curve P, the heavy line, is the power curve, obtained by multiplying the values of the e.m.f. and current for different time intervals along the line OR, when the current is lagging 30 degrees. Note that when the ordinates for curves V and A are both measured *up* from OR, they are both positive, and the product, which is the power in watts, is also positive; likewise, when both are measured downward from OR, both are negative, and the

product is positive. But between O and O' and between Q and Q', the e.m.f. and current have opposite signs; this carries the power curve below the line OR, as shown. The area under the curve of power between O' and Q and between Q' and R, represents the power of the circuit; and since $O'Q = Q'R$, the power is equal to the mean ordinate above OR multiplied by $2 \times O'Q$. Those parts of the curve below OR represent the so-called **wattless current** and represent also a direct loss in power. What happens when the voltage and current are in phase is shown by the broken line (curve) P'. Evidently, the area under this curve is considerably larger than that under the curve P. From a study of Figs. 34 and 35, it is apparent that exactly similar results would be obtained with a leading current of 30 degrees.

The smooth curves here shown are purely theoretical. In actual practice, curves V and A are very markedly different from those shown here, due to distortion of wave shape, but the principles of calculation are the same in all cases. However, Figs. 34 and 35 will serve to make clear the point that whenever the current lags or leads the voltage, there is a direct loss in power.

95. Power Factor.—The power factor of an electric circuit is the ratio of the real power of the circuit to the apparent power. Denoting the real power by kw., the apparent power by kva., and the power factor by p.f.,

$$\text{p.f.} = \frac{\text{kw.}}{\text{kva.}}$$

The power factor is almost invariably expressed as a percentage, obtained by multiplying the quotient obtained by the above division by 100; thus, if the quotient were 0.7246, the power factor would be 72.46%.

From the above equation, kw. = pf. × kva.; in other words, the real power (in kilowatts) is obtained by multiplying the apparent power (in kilovoltamperes) by the power factor. And if the power factor be 1, kw. = kva. × 1 = kva.; that is, the real power then equals the apparent power. In practically all cases—invariably in the case of pulp and paper mills and all industrial plants—the applied voltage is maintained at a constant value; consequently, the lower the power factor the greater must the the current be for the same amount of real power

Suppose a mill is running at a power factor of 50% (= 0.5); then, if the mill load is 50,000 kw., the kva. to be supplied must be kva. $= \frac{50{,}000}{0.5} = 100{,}000$. But, since the e.m.f. (the applied voltage) remains constant, the current must be doubled; *i.e.*, the current for a given load under these conditions will be twice as great for a power factor of 50% as it would be if the power factor were unity, or 100%.

The case just mentioned is an extreme one, there being very few plants running at a power factor as low as 50%. Power factors of 60% and upward to 80% are quite common, however. Bearing this in mind, the student should now be able to appreciate the tremendous commercial importance of power factor.

Suppose a power company builds a plant to supply a certain locality. The engineers of the power company will have previously made a survey of the district and will have found, say, that in addition to a residential load of purely lighting and, perhaps, heating and cooking, there will be a number of industrial plants to be supplied with power. They will make a careful estimate of the power requirements of the plants, and from these estimates, equipment will be purchased of a capacity suited to the estimated needs of the district. The transmission line will be erected and will run perhaps 100 miles or more. Transformers and substations will also be erected; then the company begins to supply its customers.

Suppose one of the customers is a paper mill and that it starts taking power from the company at a power factor of 50%. This mill is then taking twice as much current from the transmission lines as it should, but it is paying for only half of it, since the power company's bills are based on the power in *kilowatts* that the mill uses. Moreover, because of the excessive current, the power company finds that its transmission lines are too small; also, the excessive current causes a drop in voltage in the transmission, which instantly affects all the other customers. Further, the power company finds that its generators are overloaded and that its transformers and switch gear are inadequate from the same cause. Were it not that power companies penalize heavily all low power-factor customers, they would either cease to operate, or else they would be obliged continually to expend large sums of money to increase the capacity of every single piece of apparatus—from the water-

wheels or engines in the power house to the last switch on their transmission lines at the customer's plant.

Apart from the penalty exacted, the excessive current caused by a low power factor brings the company no monetary revenue; in other words, the power company is forced to supply heavy currents to its own detriment and at no cost to the customer (except the penalty). The company must also operate a larger plant than would otherwise be necessary.

Indirectly, the customer also suffers from the effects of a low power factor; he is forced (though not to the same degree) either to enlarge the size of all his cables and switch gear or have this equipment suffer from continuous overheating.

ELECTRIC MOTORS AND BOILERS

SELECTION OF MOTORS

96. Motor Types.—The motors used in the manufacture of pulp and paper belong to the following types: for alternating currents, squirrel-cage induction motors, wound-rotor induction motors, and synchronous motors; for direct currents, series motors, shunt motors, and compound-wound motors, the last two with or without interpoles.[1]

For all pulp mills, the alternating-current type of motor gives the better service, on account of its rugged construction; but for paper mills, the direct-current types find great favor where variable-speed characteristics are required. Considerations that affect the choice of a motor for particular purposes will now be discussed.

97. Squirrel-Cage Induction Motors.—By far the greater number of motors used in the various pulp processes are of the squirrel-cage induction type. These motors have no wearing parts, except the bearings; they are rugged in construction, have a high starting torque, have constant speed at any given load, and they can be made impervious to moisture, acids, and the various chemical fumes that arise in the different departments.

[1] In *Elements of Electricity*, Vol. II, Part 2, mention was made of commutating poles (also called *interpoles*) in connection with direct-current dynamos. These interpoles are also frequently used on compound-wound direct-current motors; they are smaller than the regular poles and are inserted between them, and their windings are connected in series with the armature.

The first cost, and also the cost of upkeep, is less than for any other type of motor.

Caution should be observed when deciding to install squirrel-cage induction motors above 100 h.p., because of the heavy starting current that is required; this is drawn from the supply lines and will cause fluctuations and disturbances, which are objectionable both to power companies and power users.

98. Wound-Rotor Induction Motors.—The wound-rotor induction motor is best adapted to the case where it is necessary to accelerate the speed by steps, and where a fairly high starting torque is required, as when a machine is starting up under full-load conditions. The starting current is much lower with this type than with squirrel-cage motors of the same power rating. These motors give perfect satisfaction at all ratings from 20 to 200 h.p. Above 150 h.p., however, it is usually better practice to install synchronous motors, on account of the improvement of the power factor of the system, which can be effected by these machines.

99. Synchronous Motors.—Synchronous motors should be used on all installations of 200 h.p. or over. The chief characteristic of the synchronous motor is that the power factor of the motor may be varied over a wide range; in other words, the power may be *lagging*, *leading*, *or unity*, depending on the amount of excitation to the field or rotor coils. A synchronous motor has two distinct advantages: it can be used to drive a mechanical load; it can correct the power factor of a system of induction motors; or it can perform both functions at the same time.

A disadvantage of the synchronous motor is that it cannot be used where starting under full load is required. A great many cases occur, in pulp and paper mills, however, where full-load starting is not necessary, one of the most important being in connection with grinders, where it is customary to install synchronous motors of large size, direct-connected to the stones.

In recent years, a new type of synchronous motor has been developed, known as the *supersynchronous motor*, which is capable of starting full load from rest. In construction and principle, this motor closely resembles the ordinary synchronous motor, the chief difference being that, at starting, the stator (so-called) revolves as well as the rotor. During the starting operation, the stator is gradually braked down to a standstill

and is then locked in that position, after which, the motor runs as an ordinary synchronous machine. The brakes used on supersynchronous motors are very similar to those employed on automobiles. In earlier machines, the brake was operated by means of a hand lever; but in later designs, it is operated by means of a hand wheel.

100. Direct-Current Motors.—On account of their variable speeds, direct-current motors are better adapted to paper-mill drives than alternating-current motors; and the various sections of the paper machine are nearly always driven by direct-current motors. Each section of the paper machine is provided with a separate motor, which is usually connected to it through a reduction gear. The speeds of the various sections are kept constant by means of either mechanical or electrical interlocks; and by changing the voltage of the generator or by adjusting the field strength of the section motors, the speed can be changed and kept at any desired value.

For winders, re-winders, and cutters, shunt-wound motors give good satisfaction; these motors are designed to run at any constant rate of speed between 300 and 1450 r.p.m.

Where the speed variation or load covers a wide range, direct-current, compound-wound, interpole motors are more suitable. By means of disconnecting switches, mounted at the motor terminals, the series field of the motor can be shunted out at very low speeds; the motor will then operate on its shunt field and will have all the constant-speed characteristics of the shunt-wound motor. Various degrees of over- and under-compounding may be obtained by equipping the series field of the generator supplying current to the paper-machine-drive motors with disconnecting switches, which can be opened and closed at will to suit conditions.

101. Connections for Compounding.—A diagram of the connections for a compound-wound generator, with interpoles, diverters (shunts), and disconnecting switches, to obtain any degree of compounding, is shown in Fig. 36. The generator armature, marked ARM, is here connected to three sets of poles. There may, of course, be any number of sets of poles, but three are sufficient to show the connections. The shunt field is separately excited, as usual. Note that the interpoles are so spaced as to come between the regular poles, here marked SERIES

FIELD. At low speeds, the switches A and B are closed, thus cutting out, through the diverters, both the series field and the interpoles, and the generator is run by the shunt field only. For intermediate speeds, switch A is open and switch B is closed; the generator is then run by the shunt field and the regular series field. For high speeds, both switches A and B are open;

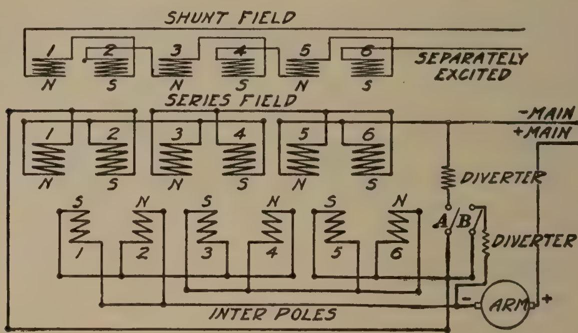

FIG. 36.

the generator is then run by the shunt field, the series field, and the additional current derived from the interpoles.

The diagram, Fig. 36, does not show the relative positions of the main poles and interpoles; the latter are smaller than the main poles and are situated between them, as indicated in Fig. 37. For a generator, the polarity here indicated would be reversed.

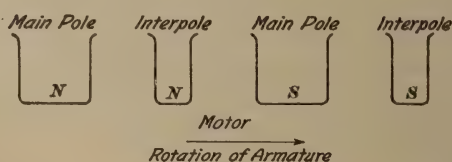

FIG. 37.

Another method of arranging the diverters in the series field and interpole field circuit is shown in Fig. 38. Here a series of switches is shown, each in a diverter circuit of varying resistance, all circuits being in parallel. These diverters supply the necessary compounding to maintain a constant voltage at any speed, regardless of the current flowing through the circuit. The shunt fields of the generator and the shunt fields of all section motors are excited from a separate direct-current generator or

exciter. The voltage, usually 125 volts, is constant, regardless of the armature current or load and of the speed of the various sections.

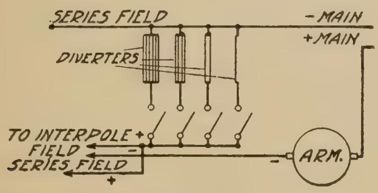

FIG. 38.

MOTOR DRIVES

102. Individual vs. Group Drives.—When laying out the various motor drives, consideration must be given to service, upkeep, and cost. Of these three items, service is most important, upkeep ranks second, and cost is least important, as compared with the other two.

Individual drives mean more motors, less shafting and belting, less expense for upkeep, but greater first cost; the reverse is the case when a group drive is used.

103. Direct Drive.—By the term *direct drive* is meant that the motor and the equipment it drives are connected through a coupling, without gears or auxiliary apparatus.

It has been found more economical to operate centrifugal pumps by direct drive, since this not only does away with line shafting and belts but also renders the units independent. In pulp and paper mills, it is not unusual to see from 8 to 10, or even more, motor-driven centrifugal pumps in one room. Some of these may be in line with each other; but, more often, they are installed to suit the piping layout. If these were driven from a line shaft, all would necessarily have to be in line, or else countershafting would be required. Again, it seldom happens that all motors are traveling in the same direction; hence, if driven from line shafting, this means the use of crossed belts, which should be avoided whenever possible.

Probably the most important item to consider when selecting a direct drive is continuity of service. For, if all the pumps in one department were driven from a line shaft by one large motor, all operation and production would cease if a belt broke, came

off, or a fuse were blown. But with individual units, if one unit shuts down, only the machine that pump is feeding is tied up. Another item to consider, but one not so important as that just mentioned, is the matter of moisture. Where pumps are delivering and pumping stock to and from stock tanks, there is more or less likelihood of the tanks overflowing; wet pulp in contact with a belt increases the slippage, and it is a common occurrence for the belt to run off the higher-speed pulley.

In the case of plunger pumps, the direct drive is not feasible; in most cases, it is impossible, since with duplex and triplex pumps, the driven pulley is between the plungers. While such a pump could be gear driven, it would be at a considerable increase in cost; hence, for this type of pump, the belt or chain drive is the more economical, though such pumps may be driven through a gear train from a motor.

In addition to centrifugal pumps, there are several other types of machines where direct-drive or direct-connected motors are advantageous. For instance, where hand barkers are used, direct drive gives better balance to the barker, and it saves space, shafting, and belting; also, in driving fans and blowers. Although it is not always possible to connect a fan direct to the motor, owing to the high rates of speed at which it travels, when the speed will allow it, a fan unit takes up less space with direct drive than with any other type.

In the case of pulp grinders, owing to the size of the motor, 600 h.p. and over, a belt drive is not to be considered, on account of the space required; here direct drive is the only type feasible. On elevator legs (loops) of the bucket type, the motor is sometimes direct-connected to the shaft in the top of the loop; to the shaft is connected the sprocket that carries and drives the chain. Since the space at the head of the loop is usually limited, direct drive is the most suitable type.

Direct drive is also used, usually with reduction gears, on agitators or mixing tanks. The drive is usually horizontal, the shaft terminating in a bevel gear at the center of the tank.

104. Gear Drives.—There are several types of gear drive, those in most common use being spur, bevel, worm, and herringbone gears. The last-mentioned type is practically noiseless in operation, and it can be run at extremely high speeds—5000 r.p.m. or over.

Where paper-machine drives are of the sectional-electric type, such as described in *Paper-Making Machines*, Volume V, Section 1, Part 6, reduction gears are much used between the motor and the particular section being driven. Although the gears occupy nearly as much space as the motor, the size of the motor frame is much smaller, owing to the higher speed; the higher the speed of the motor the smaller the size of the frame for a given horsepower output.

Bevel gears are advantageous when the direction of the drive is changed, say from horizontal to vertical, as on the agitators previously mentioned.

Back-geared motors usually have gears of the spur type; they have the advantage over most types of drives where the speed of the driven equipment is low, and where the required horsepower is small. An example is the save-all, the speed of the cylinder being 40 to 50 r.p.m., and the power required being 3 to 5 h.p. With motors of this size, with speeds of 720 to 1200 r.p.m., the cost of the motor is low, the gears cost much less than line shafting and belts, and the unit occupies very little space. This type is also used to some extent on elevator buckets, where the heat would be ruinous to a belt, as is the case with the sulphur burner.

The worm-gear drive is probably most used in operating the freight and passenger elevators of pulp and paper mills; it is the only practical type for this duty; it is also used for rotating digesters. A new type of paper-machine drive uses worm gears.

105. Chain Drives.—The chain drive has one or two advantages over the belt drive, being a much shorter drive, and there is no slip; in other words, it is a *positive* drive; it also causes less strain on the motor bearings. Its disadvantages are its cost and its speed limit, as it cannot be used where the speed is high. The speed limit for the roller chain is about 1000 feet per minute, and for a block chain, 700 feet per minute. But it is capable of transmitting greater power at low speeds than a belt of the same proportionate size, and large cumbersome pulleys are avoided.

Where the machines to be driven are exposed to the weather, as slasher saws and conveyors, the chain drive has an advantage, not only because of moisture conditions (dampness) but also because the drive can be shortened; in fact, the driving and driven sprockets may be placed as close together as the size of

the motor frame will permit. The chain drive is also the proper type to use with conveyors, because the drive is positive; with belts, the slipping and running off cause delays, which mean loss of production.

106. Belt Drives.—The principal advantage of the various kinds of belt drive is the first cost. Where the belt is not subject to injury, through the action of chemicals or moisture, it may last indefinitely, provided the load it is driving is in range of its capacity. The greater number of drives in pulp and paper mills are doubtless belt drives, principally because of the lower first cost, and partly because the belt will absorb a rather heavy shock and so protect the machine from injury. The main item in the cost of upkeep is probably labor; but since a mill has a certain number of millwrights, who are usually paid by the month, the cost of upkeep per unit is small.

In a paper mill, the greatest number of belts from one drive is the constant line. Since all units of the constant line are dependent on one another, it is the common practice to put all machines on one large motor and thus group the drives. On a 40-ton book machine, the machines in the group number from 12 to 15, and average from 2 to 35 h.p. each. The list comprises plunger, centrifugal, and suction pumps, air compressor, stock thickeners, agitators, screens, save-alls, and the shaker for the wire section. The power required for the constant-speed line is about one-fourth that for the whole machine. Link leather belting on flanged pulleys is used for supercalender drives.

ELECTRIC STEAM BOILERS

107. Reasons for Using Electric Boilers.—In many industries, there are conditions under which it is profitable to generate steam electrically by the use of electric boilers. For this purpose, hydro-electric power is generally necessary in order to compete with that derived from fuel at ordinary prices. Some of the cases where it would be advisable to use electric boilers are:

(1) Many industrial plants that use steam have also installed water-power stations for electric power. In such cases, the spare or standby generating capacity can be used during the seasons of high water. The water ordinarily going to waste over the dam can be converted into steam by the use of electric boilers, thus reducing the load on the steam-boiler plant and

effecting a direct saving in fuel. Under certain conditions, it may be found desirable to install an extra generating unit to use this excess water.

(2) Many industrial concerns purchase power on a fixed annual charge up to a certain maximum capacity. Since it is practically impossible to maintain this maximum capacity throughout the year, many kilowatt-hours of energy are paid for and not used. By the proper selection of an electric steam boiler to take care of the power purchased that is in excess of that used, a large additional return is realized on the initial investment. For example, assume that 10,000 kw. maximum demand is contracted for; but, owing to operating the plant at less than full capacity, because of lack of orders or other reasons, the load factor for the year does not average higher than 75%. This means that 2500 kilowatt-years, or $2500 \times 365 \times 24 = 21{,}900{,}000$ kilowatt-hours is being paid for and not used. If all this energy were turned into steam in an electric steam boiler, a large saving could be effected. Thus, assuming that the cost of coal were $7.50 per ton, and that from each pound 8500 B.t.u. were directly utilized in generating steam, the saving per year in coal would be

$$\frac{21{,}900{,}000 \times 1.341 \times 33{,}000 \times 60}{2000 \times 8500 \times 778} = 4400 \text{ tons;}$$

and the saving in money would be 4400 × $7.50 = $33,000.

(3) During the off-peak period of the day, some power stations have an excess of water for power purposes that might be wasted because of lack of storage capacity; at the same time, the boilers must be kept up under pressure to take the peak loads. When oil is used for fuel under these conditions, the fire could be put out, and the boilers could be kept under pressure by supplying them with steam from an electric boiler.

(4) In industrial plants, there are often instances where comparatively small amounts of process steam are required at a considerable distance from the boiler house. It will often be found more profitable to transmit electric power from the generating plant and install an electric steam boiler at the point of utilization than to transmit the steam long distances.

(5) Another application, made in both Canada and the United States, is for those central power stations that have excess energy to install and maintain electric steam boilers in industrial plants, and to sell the energy on the basis of metered steam.

By the use of suitable auxiliary apparatus, it is possible so to maintain constant steam pressure, constant temperature, constant power input, or variable power input, that the electric steam boiler will absorb all excess power above that required in other parts of the mill.

108. Principle of Operation.—While the principle of operation is practically the same in all electric boilers, the details of construction vary considerably with different manufacturers. The principle employed is to utilize the resistance of the water in the boiler in order to generate heat and thus evaporate the water into steam.

Practically all electric steam boilers of over 100-h.p. capacity are simply steel shells containing water, in which are immersed electrodes that pass the electric current through the water. This apparatus is further described in Part 5 of this Section. Voltages in use range from 500 volts on the smaller units, of about 1000 kw., to 13,000 volts on the largest boilers, of 20,000-kw. capacity.

The efficiency of electric steam boilers is very high, averaging about 97%, as against an average efficiency of about 66% for fuel-fired boilers.

One boiler horsepower (abbreviated b.h.p.) is defined as the equivalent evaporation of 34.5 pounds of water from and at 212°F. For approximate calculations, 1 pound of steam may be assumed to contain 1000 B.t.u. Since,

$$1 \text{ kw.h.} = \frac{1000 \times 33{,}000 \times 60}{746 \times 778} = 3413 \text{ B.t.u.},$$

$$1 \text{ b.h.p.} = 34.5 \times 1000 = 34{,}500 \text{ B.t.u.} = \frac{34{,}500}{3413} = 10 \text{ kw., nearly.}$$

Consequently, when considering the installation of electric steam boilers, assume that 10 kw. are equivalent to 1 b.h.p.

The power factor of electric boilers is practically unity in all cases.

TROUBLES AND REMEDIES OF ELECTRICAL EQUIPMENT

109. Method of Treating the Subject.—Under the heading, Troubles and Remedies of Electrical Equipment, are included the troubles of induction, synchronous, and direct-current motors, direct-current generators, compensators, and transformers that

are commonly met with in practice, together with the symptoms that indicate the troubles, the causes that produce them, and the remedies to be applied. The subject is treated in much the same manner that a physician would treat a patient: *viz.*, from the symptom, the trouble is diagnosed or inferred; knowing the trouble, experience indicates the cause, knowing which, the remedy can be prescribed. For convenience of reference, each particular piece of apparatus is treated separately, though this may cause a little repetition, and each symptom is numbered, all numbers beginning with (1) for each piece of apparatus.

110. Induction, Synchronous, and Direct-Current Motors and Dynamos.—The following symptom, with its various troubles, causes, and remedies, applies to any induction, synchronous, and direct-current motor and dynamo: **Symptom:** Bearing smoking or too hot to touch. **Trouble:** This symptom may manifest itself as the result of any of the following troubles, for each of which, the cause and remedy is given. (**a**) Bearing is dry. **Cause:** Insufficient oil, or oil rings not working. (**b**) Bearing dirty. **Cause:** Grit in oil. **Remedy:** For (**a**) and (**b**), refill with clean oil after first washing the bearing with kerosene. **Trouble** (**c**): Bearing tight. **Cause:** Same as for (**a**) and (**b**), which results in particles of metal being sheared off and deposited at other parts. **Remedy:** Scrape bearing and shaft, or replace bearing. **Trouble** (**d**): Oil rings not working. **Cause:** Rings out of slots. **Remedy:** Replace rings, making sure that no metal adheres to sides of slot. If ring sticks or runs slowly, bevel it at either top or bottom with a fine file. **Trouble** (**e**): Bearing binding. **Cause:** Shaft out of true. **Remedy:** Place shaft in a lathe, and true and renew bearing. **Trouble** (**f**): Bearing out of true. **Cause:** Too great pull on pulley. **Remedy:** Bearing should be shimmed with pieces of tin, as a temporary measure, or replaced with new bearing. **Trouble** (**g**): Loose bearing. **Cause:** Vibration. **Remedy:** Tighten the set screws that hold bearing in journal.

NOTE.—Never use ice or water on a bearing unless the machine is kept running; it is liable to spring the shaft.

INDUCTION MOTORS

111. Troubles of Induction Motors.—The following symptoms, troubles, causes, and remedies apply to induction motors.

(1) **Symptom**: Bearing hot, but no hotter than other parts of motor. **Trouble**: Heat transferred from rotor or stator of motor. **Cause**: Overload on motor. **Remedy**: Decrease load, or increase size of motor.

(2) **Symptom**: Smoke issues from windings; a part of the windings is hot and the remainder is cool; wedges over coils are charred. **Trouble**: Displaced air gap, or rotor is not centered in stator. **Cause**: Bearing worn on one side. **Remedy**: If noticed before coils are damaged, re-alining the bearing and inserting new wedges will correct the fault; otherwise, the coils will require to be replaced.

(3) **Symptom**: Every second coil in a two-phase motor, and every third coil in a three-phase motor, hotter than adjacent coils. **Trouble (a)**: Not enough resistance in phase that is hottest, causing unbalanced currents in phases. **Cause**: One or more coils of one phase short circuited within themselves. **Remedy**: Replace the short-circuited coil, or "jump" the coil[1] as a temporary expedient. **Trouble (b)**: One phase grounded. **Cause**: Dampness, or damage by foreign material. **Remedy**: Remove ground by lifting coil and re-insulating. One ground is not serious when delta connected (see Art. **125**), if motor is not overloaded; when star connected (see Art. **125**), there may be unequal currents between phases. If two phases are grounded, a short circuit results.

(4) **Symptom**: Motor runs hot, and on examination, it is found that the groups of two-phases of a star-connected motor, and the groups of one-phase of a delta-connected motor, are hotter than other groups. **Trouble**: Motor running single phase. **Cause**: One fuse blown, or one overload relay out of order. **Remedy**: Replace fuse, or adjust relay, and take ammeter readings of each phase.

(5) **Symptom**: Motor runs hot; explosions, sometimes accompanied by fire, occur in the windings. **Trouble**: Temporary ground or short circuit. **Cause**: Due to dampness, which causes circulating currents between coils and between any coil and

[1] Care must be used in jumping a coil, and the following points should be observed: Where a phase-boundary coil is cut out or jumped, care must be taken that no interconnection of phases or wrong groups takes place. In one-layer windings, if the insulation is badly burnt, the coil must be completely taken out; because, if only disconnected, circulating currents will be produced that will heat the jumped coil and damage the adjacent coils. This is due to there being only one coil side per slot. If more coils than one phase are burnt, care must be taken that there are enough left to offer sufficient resistance to keep the current low, on account of excess heating.

ground. **Remedy:** (1) Bake motor until all dampness disappears, and dip or brush with insulating varnish. (2) If coils are punctured, replace with new coils. (3) If motor is needed at once, the punctured coils may be cut out, if not too many, as a temporary expedient.

(6) **Symptom:** Motor runs hot and all stator coils have same temperature. **Trouble:** Motor usually overloaded. **Cause:** Motor overloaded. **Remedy:** Test each phase with an ammeter; if the readings are high, reduce the load or increase the size of the motor.

(7) **Symptom:** One or more phases hot in spots, but cool in others. **Trouble:** A part of the windings inoperative. **Cause:** Short circuits between adjacent stator coils. **Remedy:** Replace short-circuited coils, as they will usually be found badly charred.

(8) **Symptom:** Motor refuses to start, with starter handle in starting position, although the motor issues a humming sound.[1] **Trouble (a):** Motor tries to run single phase. **Cause:** One fuse blown, or one overload relay out of order. **Remedy:** Replace fuse, or adjust relay, **Trouble (b):** Air gap displaced.[2] **Cause:** Bearing out of true. **Remedy:** Shim the bearing, or replace it with a new one. **Trouble (c):** Open circuit in stator windings. **Cause:** Caused either by a short circuit that will puncture a coil, or from rough handling. **Remedy:** Insert new coil, or "jump" the damaged one.

(9) **Symptom:** Motor starts and runs, but rotor heats up although stator is cool. **Trouble:** Abnormal currents in rotor. **Cause:** Rotor bars loose, or grounded. **Remedy:** Tighten the set screws that hold rotor bars to short-circuiting rings, and solder or weld them, and remove grounds. In more up-to-date types of rotors that have cast-on end rings, this trouble is seldom encountered.

[1] The following hints will be found useful in locating the trouble: If the motor does not start, (1) examine the fuses: (2) examine the relays; (3) look over the starter carefully; (4) inspect air gap with a feeler; (5) remove belt or coupling, as case may be, to find if motor is overloaded; (6 test out motor windings with a magneto or bank of lamps. One of these suggestions should serve to locate the trouble; then, by applying the proper remedy, the difficulty is soon removed.

[2] When a rotor is not centered in the stator, it is possible that a motor cannot develop sufficient torque; consequently, it will not run, even though all fuses are intact. The motor will hum, and the rotor will probably turn an inch or so. The symptom is the same as that of a motor trying to run single phase. In a case of this kind, insert a feeler between the rotor and stator, and the trouble will show up as an irregular air gap.

(10) **Symptom:** Motor issues a peculiar sound when running light, as though a heavy load were thrown on periodically, with slight slackening of speed at these intervals. **Trouble:** One coil in phase reversed. **Cause:** Due to wrong connection when being repaired or re-connected. **Remedy:** Connect coil to its proper group, and in proper polarity.

(11) **Symptom:** Motor issues a buzzing sound when fully loaded. **Trouble:** Loose connection in rotor bars. **Cause:** Overheated bars or rings. **Remedy:** Same as for Symptom (9).

(12) **Symptom:** Wound-rotor motor runs half speed. **Trouble:** One collector-ring lead broken or disconnected. **Cause:** Mechanical injury, or due to vibration. This fault has the same effect as doubling the number of poles. **Remedy:** Replace broken or loose connection.

SYNCHRONOUS MOTORS

112. Troubles of Synchronous Motors.—The following are some symptoms and troubles of synchronous motors, their causes, and their remedies.

(1) **Symptom:** Bearing hot, but no hotter than other parts of motor. **Trouble:** Heat transferred from rotor or stator of motor. **Cause:** (1) Overload on motor. **Remedy:** Decrease load, or increase size of motor. (2) Motor field over excited. **Remedy:** Increase strength of field by lowering excitation.

(2) **Symptom:** Stator windings hot at certain spots, enough, probably, to cause smoking; wedges over coils charred. **Trouble:** Displaced air gap, or rotor not centered in stator. (Since the air gap in a synchronous motor is greater than in an induction motor, this trouble is seldom met with, although the bearings may become worn.) **Cause:** Bearings worn on one side. **Remedy:** If noticed before coils are damaged, re-alining the bearings and inserting new wedges will correct this fault; otherwise, the coils will require to be replaced.

(3) **Symptom:** Motor fails to start. **Trouble:** Insufficient torque. **Cause (1):** Voltage too low. **Remedy:** Increase the line voltage. The torque varies as the square of the applied voltage; *i.e.*, if the voltage is doubled, the torque is increased $2^2 = 4$ times. Raising the compensator taps may help if the motor is not too large; but since this also increases the starting current, it tends further to decrease the voltage. **Cause (2):**

Open circuit in stator windings, due to short circuit, rough handling, or wrong connection. **Remedy:** Repair break by jumping the coil or coils causing the trouble, or replace damaged coil. **Cause (3):** Friction of bearings too great. **Remedy:** Scrape or replace bearings if broken, or relieve pressure between bearing and shaft by loosening journal studs. **Cause (4):** Mechanical load too great. **Remedy:** Remove a part of the load, or install clutch coupling between motor and load. **Cause (5):** Wrong connection in compensator; one phase usually reversed. **Remedy:** Make proper connection in compensator.

(4) **Symptom:** Motor starts, but fails to come up to speed. **Trouble:** Insufficient torque. **Cause (1):** Rotor field in circuit with exciter, due to discharge switch being in wrong position; this creates a separate flux, which opposes the alternating flux of the stator windings. **Remedy:** Open the circuit between the exciter and motor fields. **Cause (2):** Mechanical load too great. **Remedy:** (*a*) Open discharge resistance. (Care must be exercised in employing this method, and resistance circuit must be closed before shutting down; otherwise the field windings may be damaged.) (*b*) Raise the line voltage. (*c*) Increase the squirrel-cage winding on the rotor. (*d*) Install a clutch coupling. **Cause (3):** Not enough "bridges" or bars in squirrel-cage winding. **Remedy:** Same as for Cause (2).

(5) **Symptom:** Motor comes up to near synchronous speed but cannot be thrown on line; (**b**) motor fails to synchronize; (**c**) circuit breaker trips out when line voltage is impressed on motor. **Trouble:** Trouble in exciter circuit. **Cause (1):** Open circuit in rotor field. **Remedy:** Test out with low voltage, or with magneto. **Cause (2):** Open circuit in exciter field, or between exciter and motor field. **Remedy:** Same as for (1). **Cause (3):** Open circuit in exciter armature. (The circuit between rotor and exciter is not broken in a case of this kind, but the current is interrupted and decreased.) **Remedy:** Bridge the open circuit by connecting a piece of wire to commutator bars each side of break. **Cause (4):** Faulty brushes on exciter, causing the same trouble as in (3). **Remedy:** Adjust brushes if out of line; renew brushes if broken or worn; increase tension between commutator and brushes, and clean commutator. **Cause (5):** Open circuit in motor field rheostat; open circuit in exciter field rheostat. **Remedy:** Test with magneto, and repair break. **Cause (6):** Field discharge switch fails to

make proper contact. **Remedy:** Clean contacts; if they are badly pitted, renew them. **Cause (7):** Short circuit in one or more field coils. **Remedy:** Test with low voltage and compass, and repair or renew damaged coil. **Cause (8):** Reversed coil rotor field circuit. (A fault of this kind cannot happen while motor is running; it would be due to a wrong connection while repairs were being made to the rotor. All the other faults, however, could occur while motor was running, due to careless operation, to foreign material being drawn into the motor by suction, or to damage to the exciter and wiring.) **Remedy:** Test with low voltage and compass, and reverse connections on coil causing the trouble. (In connection with the last two remedies, low direct-current voltage is applied to the field windings, and a compass is held to each pole in case of a short circuit; the short-circuited pole will give no deflection of the compass needle, but with a reversed coil, the deflection is in a direction opposite to what it should be. In other words, instead of adjacent north and south poles, there will be two north or two south poles together.)

(6) **Symptom:** Stator windings hot at all parts. **Trouble (a):** Mechanical overload. **Cause:** Mechanical overload. **Remedy:** Remove a part of the load, or increase the size of the motor. **Trouble (b):** Low power factor. **Cause:** Over excitation of the field coils. In this case, the low power factor is *leading;* it has the same effect as a low lagging power factor, because the current and voltage are out of phase in the same proportion. **Remedy:** Adjust field excitation until the current in the stator is a minimum; this will increase the power factor of the motor, but will lower the power factor of the system.

(7) **Symptom:** One or more coils in stator have been heated so hot that the insulation is completely burned off. **Trouble:** Short circuit in one or more coils. **Cause:** Due to mechanical injury, or to broken-down insulation caused by an overload. **Remedy:** Jump the injured coil as a temporary expedient, or replace with a new coil.

(8) **Symptom:** Motor issues a peculiar humming sound, the volume of which increases and decreases at certain intervals. (Motor may even slow down and stop, or trip circuit release, in a case of this kind.) **Trouble:** Motor "hunting." **Cause:** (*a*) Unstable speed of prime mover on alternator supplying motor; (*b*) high resistance in line between alternator and motor, due to

long transmission line. **Remedy:** If speed of prime mover cannot be properly regulated, adding more squirrel-cage windings will correct the fault.

(9) **Symptom:** Motor issues a harsh, buzzing sound, which remains constant in its volume. **Trouble:** (*a*) Short-circuited coil or group; (**b**) open circuit. **Cause:** Same as for Symptom (8); or (**b**) may be due to a short circuit that would burn out the coil and cause an open circuit. **Remedy:** Same as for Symptom (8). **Trouble (c):** Grounds. (One ground might cause a heavy current to flow in the grounded phase, depending on what part of the winding the ground occurred.) **Cause:** Dampness, or same as for (**a**) and (**b**). **Remedy:** Remove ground as soon as possible by lifting affected coil and re-insulating it. One ground is not serious, but it is liable to cause others, and two grounds in the same motor is a short circuit. **Trouble (d):** Reversed coil or group. **Cause:** Due to wrong connection when making repairs. (A reversed coil or group will not prevent a motor from starting, coming up to speed, or running.) **Remedy:** Test with low-voltage direct current and a compass, and change the connections on the reversed coil or group.

(**10**) **Symptom:** Motor trips its circuit breaker and shuts down, although the induction motors of the same system keep running. **Trouble (a):** Surge on line. **Cause:** (1) Momentary high voltage, due to speed of alternator; (2) lightning discharge during a storm. **Remedy:** No remedy. Line is usually itself again in a few seconds, when motor can again be started. **Trouble (b):** Low voltage. **Cause:** Momentary slowing down of alternator. **Remedy:** Same as for (**a**). **Trouble (c):** Excitation ceases while motor is carrying a heavy mechanical load. **Cause:** Open circuit between exciter and motor field; exciter not operating. **Remedy:** If exciter voltmeter gives a reading, the trouble is in the motor field, in the motor field rheostat, or in wiring connecting the exciter and motor field. If the exciter voltmeter does not give a reading, the trouble is in the exciter. Examine brushes, field coils, armature, and exciter field rheostat.

(**11**) **Symptom:** Motor issues a loud growling sound, easily distinguished from those before mentioned, and motor acts as if overloaded, though direct-current meters show no over excitation. **Trouble:** Rotor out of magnetic center of stator. **Cause:** (1) Motor not level; (2) shaft collars shifted; too great end play of shaft. **Remedy:** (1) Level motor bedplate; (2) adjust collars

for proper end play. (The cores of synchronous motors are narrow in comparison with induction motors.)

DIRECT-CURRENT DYNAMOS AND MOTORS

113. Troubles of Direct-Current Dynamos and Motors.—The following are some symptoms and troubles of direct-current dynamos and motors, their causes, and their remedies.

(1) **Symptom**: Bearing hot, but no hotter than other parts of the frame. **Trouble**: Heat transferred from armature. **Cause**: Overload on dynamo or motor. **Remedy**: Decrease load, or increase size of dynamo or motor.

(2) **Symptom**: Sparking of brushes.

Trouble (a): Brushes not diametrically opposite one another. **Cause**: Brush-holder studs loose, or not set properly in the first place. **Remedy**: Measure with a tape; or count commutator segments, and adjust brushes on diametrically opposite bars.

Trouble (b): Brushes not set on neutral point in relation to the field. **Cause**: Setscrew holding rocker arm may have become loose, or rocker arm may have shifted through carelessness. **Remedy**: Shift rocker arm and brushes ahead, or in direction of rotation, for a dynamo; shift backwards, or against direction of rotation, for a motor.

Trouble (c): One or more brushes in contact with wrong number of commutator bars. **Cause**: One or more brushes thicker than others. **Remedy**: Trim all brushes to the same thickness.

Trouble (d): Brushes cover too many bars. **Cause**: Brushes too thick for the particular design of dynamo or motor. **Remedy**: Use proper brushes, or grind those in use to proper thickness.

Trouble (e): Brushes out of line. **Cause**: Brush holders not set properly on studs. **Remedy**: Adjust holders so they will line up properly.

Trouble (f): Brushes too short. **Cause**: Wear. **Remedy**: Replace with new brushes.

Trouble (g): Poor contact between brush and commutator. **Cause**: (1) oil and grit on commutator. **Remedy**: Clean commutator with a dry rag. (Never use waste.) (2) Flint, or other hard substance, in brush. **Remedy**: Sandpaper the brush, to remove the foreign matter, keeping it the shape of the commutator. (3) Brushes not trimmed properly. **Remedy**: Place

a piece of sandpaper under brush, with smooth side flat on commutator, and work back and forth until brush fits commutator at all points. (Do not use emery cloth or paper.)

Trouble (h): Rough commutator. **Cause**: Vibration; uneven brushes; bars of different qualities; uneven ridges, where brushes do not touch commutator. **Remedy**: If taken in time, the commutator may be trued by using a wooden block, hollowed out to the shape of the commutator, and in which a piece of sandpaper is placed. (Do not use emery cloth or paper.) The use of a commutator stone is recommended in preference to sandpaper. If commutator is too rough, it should be trued in a lathe. (Clean all copper dust from commutator before putting it back into service.)

Trouble (i): High commutator bars. **Cause**: The jam nuts and rings that hold segments in place are loose. **Remedy**: Carefully drive the high bars back into place, and tighten rings and jam nuts; smooth commutator with sandpaper or stone, as outlined for (*h*).

Trouble (j): Low commutator bars. **Cause**: Rough handling or wearing away; due to bars being soft, or from a short-circuited coil. **Remedy**: Loosen the jam nuts and ring; lift the bars even with the others, if possible, and true the commutator.

Trouble (k): Loose commutator bars. **Cause**: Loose clamping ring and jam nuts. **Remedy**: Tighten ring and jam nut, and true commutator, as outlined in (*j*).

Trouble (l): High mica. **Cause**: Copper wears faster than mica. **Remedy**: Under cut the mica below the surface of the bars. See that all dust is removed before putting machine back into service.

Trouble (m): Weak magnetic field. **Cause**: Open circuit in field; short circuit in field. **Remedy**: Repair or rewind, as the case may be.

Trouble (n): Excessive current in armature. **Cause**: Too much load on machine. **Remedy**: (1) Reduce electrical load. (2) Reduce mechanical load.

Trouble (o): Ground on machine or in line. **Cause**: Defective insulation. **Remedy**: Remove ground, if possible; or, cut out the grounded coil or rewind the grounded part.

Trouble (p): Short circuit in (1) armature of dynamo or motor, or (2) on line supplied by dynamo. **Cause**: Defective insulation. **Remedy**: For (1), cut out short-circuited coil and bridge adjacent

commutator bars as a temporary measure. For (2), remove short circuit on line. If equipped with proper fuses, a short circuit on the line will blow the fuse and protect the dynamo.

Trouble (q): Voltage too high. **Cause**: (1) Revolutions per minute of armature too high; (2) armature current too great. **Remedy**: For (1), reduce speed of prime mover. For (2), cut more resistance in field circuit.

Trouble (r): Armature current of motor too great. **Cause**: (1) motor overloaded; (2) controller of wrong type for the motor. **Remedy**: For (1), reduce mechanical load. For (2), substitute proper controller for the one in use, one having the right amount of resistance for controlling the armature current.

Trouble (s): Commutator bars short circuited; mica worn or eaten away, causing deep pits between bars. **Cause**: (1) copper or carbon dust between bars; (2) melted solder from leads between bars; (3) insulation between brushes and holders broken down. The last also causes a ground on the machine. **Remedy**: For (1) and (2), remove foreign matter from commutator. For (3), Repair insulation.

Trouble (t): Open-circuited armature coils. **Cause**: (1) Conductor burned by short circuit; (2) heat melts solder in connection at commutator bar. **Remedy**: For (1), bridge the open circuit by connecting the commutator bars adjacent to the break; or, stagger the brushes in all brush holders where there are two or more in line, so as to cover the break. (When jumping an open circuit of this kind, be careful not to short circuit a good coil; this will aggravate the sparking, and will also ruin the coil.) For (2), re-solder the connection.

Trouble (u): Reversed armature coil. **Cause**: Cross connection to wrong commutator bars. **Remedy**: Test polarity with a compass, and connect to proper bar.

Trouble (v): Blowholes in frame. **Cause**: Improper casting. **Remedy**: Return machine to factory. A trouble of this kind is hard to locate; but if all other remedies have failed, this may be the cause.

(3) **Symptom**: Rings of fire follow the brushes around the commutator. **Trouble**: Short-circuited armature coil; open-circuited armature coil. **Cause and remedy**: Same as for (*p*) and (*t*), Symptom (2).

(4) **Symptom**: Flashing, or excessive arcing from brush to brush. **Trouble** (a): Excessive voltage impressed on motor.

Cause: (1) High voltage on line; (2) motor may be built for voltage lower than that impressed on it. **Remedy**: For (1), reduce voltage, if possible; for (2), change motor for one that operates on higher voltage, or change setting of brushes. (Motors are sometimes designed for two voltages.) **Trouble** (b): Short circuit in dynamo line. **Cause**: Usual short-circuit causes. **Remedy**: Remove the cause; if line is properly protected, fuses will blow.

(5) **Symptom**: Singing of brushes. **Trouble** (a): Brush pressure too great. **Cause**: Brush holders not properly adjusted. **Remedy**: Lessen the tension of brush-holder springs. (Brush pressure on commutator should be 1.5 pounds per square inch.) **Trouble** (b): Brushes too hard. **Remedy**: Replace brushes with those of softer material; the use of graphite brushes will eliminate singing. (A small quantity of vaseline, placed on a clean cloth, and rubbed on the commutator, will help reduce the singing; the commutator should be wiped dry immediately afterwards.)

(6) **Symptom**: Chattering of brushes. **Trouble** (a): High bars; low bars; high mica; loose bars. **Cause and remedy**: Same as for Troubles (*i*), (*j*), (*k*), and (*l*), Symptom (2).

Trouble (b): Brushes set at improper angle for direction of rotation. **Cause**: Wrong direction of rotation. **Remedy**: Reverse angle of brush setting; or, change polarity of dynamo, and reverse direction of rotation of prime mover. (Do not cross a belt.)

Trouble (c): Improper end play. **Cause**: Shaft collars not properly set. **Remedy**: Reset collars and readjust end play. End play should not be less than $\frac{1}{16}$ inch or greater than $\frac{1}{4}$ inch.

Trouble (d): High ridges on commutator. **Cause**: Not enough end play. **Remedy**: Same as for Trouble (*c*). Remove ridges by turning in a lathe, or by using a commutator stone.

(7) **Symptom**: Blackening of commutator at certain spots. **Trouble**: Short circuit in armature; open circuit in armature. **Cause and remedy**: Same as for Troubles (*p*) and (*t*), Symptom (2).

(8) **Symptom**: Armature hot all over. Trouble (a): Overload on motor or dynamo. **Cause**: Overload. **Remedy**: Reduce electrical load; reduce mechanical load. **Trouble** (b): Moisture in coils. **Cause**: Operating in damp place. **Remedy**: Dry out by running with light load; or, bake in oven. **Trouble** (c): Armature out of center between poles. **Cause**: Bearing worn on

one side. **Remedy:** Replace bearing, or shim the one in use. **Trouble (d):** Eddy currents in armature core. **Cause:** Faulty connection. **Remedy:** Rebuild core, using thinner sheets or laminations. (This last trouble is seldom encountered.)

(**9**) **Symptom:** Armature hot in some spots and cool in others. **Trouble (a):** Short-circuited coil or coils; open-circuited coil or coils. **Cause and remedy:** Same as for Troubles (*p*) and (*t*), Symptom (2). **Trouble (b):** Reversed polarity of armature coils. **Cause:** Cross connection. **Remedy:** Re-connect reversed coils to proper bars.

(**10**) **Symptom:** Armature issues a pounding sound. **Trouble:** Armature striking or rubbing against pole piece. **Cause:** Bearing worn on one side. **Remedy:** Shim the bearing; or, replace bearing with new one.

(**11**) **Symptom:** Armature issues a loud humming sound. **Trouble:** Path of magnetism spread out too much. **Cause:** Pole shoes too flat. **Remedy:** Chamfer the pole pieces, so as to reduce the area of the path of the magnetic flux; reduce the magnetic field. (This trouble will not occur in a modern machine.)

(**12**) **Symptom:** Series field coils hot. **Trouble (a):** Excessive current. **Cause:** Coils wound with too much wire or too small wire. **Remedy:** Increase size of wire, reduce winding, or reduce current. **Trouble (b):** Moisture in coils. **Cause:** Dampness. **Remedy:** Bake coils in an oven; or by passing a light current through them. **Trouble (c):** Speed too low. **Cause:** (1) Prime-mover speed too low. **Remedy:** Increase speed of prime mover; increase size of driving pulley; decrease size of driven pulley. **Cause:** (2) Too much resistance in series with armature. **Remedy:** Cut out resistance. **Trouble (d):** Partial short circuit in one or more field coils. **Cause:** Moisture in coils. **Remedy:** Dry out coils, and rewind if necessary. **Trouble (e):** Brushes not on neutral point. **Cause:** Brushes shifted through accident, or not set properly in first place. **Remedy:** Shift rocker arm until minimum sparking occurs. **Trouble (f):** Overload. **Cause:** Overload. **Remedy:** Reduce load on either dynamo or motor.

(**13**) **Symptom:** Shunt field coils hot. **Trouble:** Excessive current. **Cause:** (1) Partial short circuit. **Remedy:** Test out as described elsewhere, and rewind. (2) Not enough turns in winding. **Remedy:** Add more turns; or wind with wire of smaller size; or add external resistance. (3) Voltage too high. **Remedy:** Decrease voltage by decreasing speed. (4) Brushes not on neu-

tral point. **Remedy:** Shift rocker arm until minimum sparking occurs. (5) Moisture in coils. **Remedy:** Dry out coils, and rewind if necessary. (6) Overload. **Remedy:** Remove a part of the load.

(**14**) **Symptom:** Pole pieces hotter than field coils. **Trouble** (**a**): Eddy currents. **Cause:** Faulty construction. **Remedy:** Replace with laminated poles, if necessary. **Trouble** (**b**): Fluctuating current through fields. **Cause:** Unstable load. **Remedy:** Provide field circuit with automatic regulator.

114. Troubles Peculiar to Direct-Current Motors: The following symptoms and troubles, with their causes and remedies, are peculiar to direct-current motors only.

(**1**) **Symptom:** Series motor runs away. **Trouble:** Armature current too great. **Cause:** It is the nature of a series motor to accelerate its speed if the load is decreased, or if a belt comes off. This is caused by the building up of increased flux in the field, which creates an increase of current in both field and armature. **Remedy:** A series motor should be provided with a regulator to control the field current, whether operated on a constant current or a constant potential circuit; when operating on a constant current, a rheostat connected in shunt with the armature will provide a remedy. (Do not shunt the field with the rheostat, because this tends to increase the speed.)

(**2**) **Symptom:** Shunt motor runs too fast. **Trouble** (**a**): Field too weak. **Cause:** Rheostat not properly adjusted to the field. **Remedy:** Strengthen the field by cutting out field resistance; or, increase the resistance of the armature by cutting in the armature rheostat. **Trouble** (**b**): Voltage too high. **Cause:** Dynamo voltage too high. **Remedy:** Reduce dynamo voltage; or, insert a resistance in series with the armature.

(**3**) **Symptom:** Shunt motor runs too slow. **Trouble** (**a**): Motor overloaded. **Cause:** Motor overloaded. **Remedy:** Reduce load, or increase size of motor. **Trouble** (**b**): Short circuit in armature. **Cause:** Insulation broken down in slots or where leads cross one another. **Remedy:** Trace the trouble and repair if possible; or cut out damaged coil by "jumping" or connecting bars adjacent to the short-circuited coil, as a temporary remedy; or rewind armature. (A short-circuited coil is hotter than its neighbors.) **Trouble** (**c**): Armature rubbing pole pieces. **Cause:** Bearing worn on one side. **Remedy:**

Replace bearing and line up air gap to the same thickness on all sides. **Trouble** (**d**): Friction. **Cause**: Bearings too tight. **Remedy**: Remove bearings and scrape until the shaft turns freely. **Trouble** (**e**): Voltage too low. **Cause**: (1) Dynamo voltage too low. **Remedy**: Increase voltage by increasing speed of dynamo or by cutting out resistance from dynamo field circuit. (2) Too much resistance in armature circuit of motor. **Remedy**: Cut resistance out of armature circuit, or increase resistance of field circuit. (The action of a rheostat in the armature circuit is exactly opposite to that of the field circuit of a shunt, series, or a compound-wound motor.)

(**4**) **Symptoms**: Motor fails to start. **Trouble** (**a**): Load too great. **Cause**: Load too great. **Remedy**: Disconnect load to see if motor will start light.

Trouble (**b**): Friction. **Cause**: Bearing too tight. **Remedy**: Scrape the bearing and see if shaft turns easily.

Trouble (**c**): Fuse blown. **Cause**: Overload or short circuit. **Remedy**: Replace fuse and try again.

Trouble (**d**): Open circuit in line. **Cause**: Wires broken or disconnected. **Remedy**: Examine line and connections, and repair if this is the trouble; test line to motor terminals with magneto.

Trouble (**e**): Open circuit in fields or field connections. **Cause**: Rough usage; or, original short circuit, which may have burned a coil or connection. **Remedy**: Examine field connections and test with a magneto or voltmeter; if coil is open, rewind.

Trouble (**f**): Open circuit in armature. **Cause**: Same as for Trouble (*e*). **Remedy**: Test out adjacent commutator bars, and locate the trouble; bridge the gap as a temporary measure; rewind the coil or the entire armature. (The motor may show a tendency to run if brushes do not rest on open-circuited bar.)

Trouble (**g**): Short circuit in fields. **Cause**: Dampness or defective insulation. **Remedy**: Bake if caused by dampness; rewind if defective insulation. (Where there are more than two field coils, the motor may show a tendency to start; but it will not run properly with load. If motor is bi-polar, it will not start.)

Trouble (**h**): Short circuit in armature. **Cause**: Carbon dust between adjacent bars; insulation or coils broken down. **Remedy**: Clean commutator. The presence of this trouble will be denoted by flashing of brushes, or by the heating of one or more coils; rewind if insulation is gone.

Trouble (i) : Brushes not in contact with commutator. **Cause**: Brushes fit too tightly in holders, or holders are loose. **Remedy**: Adjust brush so it works easily in holder, and tighten holder in its proper place.

Trouble (j) : Poor commutation. **Cause**: Brushes not set on neutral point. **Remedy**: Move rocker back into neutral position.

(**5**) **Symptom**: Motor runs backwards. **Trouble**: Reversed connection. **Cause**: Reversed connection. **Remedy**: (1) On series motor, reverse either the field or the armature. (2) On shunt motor, reverse only the field. (3) On compound-wound motor, reverse both fields.

115. Troubles Peculiar to Direct-Current Generators.—The following troubles, with their causes and remedies, are peculiar to direct-current generators (dynamos) only.

(**1**) **Symptom**: Dynamo fails to build up. **Trouble** (**a**) : Residual magnetism destroyed. **Cause**: Residual magnetism lost through non use. **Remedy**: Charge fields with another generator or with a battery of dry cells, making sure that the fields are connected for proper polarity.

Trouble (**b**) : Residual magnetism reversed. **Cause** (**1**): Reversed current through field coils; earth's magnetism. **Remedy**: Connect fields for proper polarity; run machine above rated speed; short circuit the armature at the brushes; or tap the poles with a hammer. Usually, any one of these remedies will cause the dynamo to build up. However, if these methods fail, the remedy for Trouble (*a*) must be applied. The polarity should be tested with a compass, both before and after applying the remedy. **Cause** (**2**): Proximity of another dynamo. **Remedy**: Same as preceding. Move dynamo to another location; or connect the two dynamos so they will not affect each other. **Cause** (**3**): Brushes so shifted that commutation is in opposite direction. **Remedy**: Shift brushes in direction of rotation, or back and forth, until dynamo builds up.

Trouble (**c**) : Short circuit in armature. **Cause and remedy**: Same as for Trouble (*h*), Symptom (4), Art. **114**.

Trouble (**d**) : Open circuit in armature. **Cause and remedy**: Same as for Trouble (*f*), Symptom (4), Art. **114**.

Trouble (**e**) : Short circuit in field. **Cause and remedy**: Same as for Trouble (*g*), Symptom (4), Art. **114**.

Trouble (f): Open circuit in field. **Cause and remedy:** Same as for Trouble (*e*), Symptom (4), Art. **114.**

Trouble (g): Short circuit in external circuit. **Cause:** Lamp socket, motor, or line short circuited. **Remedy:** Search for the trouble by sectionalizing the line, and remove the cause. In a case of this kind, the dynamo will try to build up, and the commutator and brushes will flash. If properly protected by fuses, the machine will clear itself from the line.

Trouble (h): Fields opposed to each other. **Cause** (**1**): The field coils of either a shunt-wound or series-wound dynamo are connected for the same polarity. **Remedy:** Change connections between field coils, and test with a compass for opposite polarity of adjacent coils. If this is the trouble, the dynamo should build up when the adjacent coils show opposite polarity. **Cause** (**2**): Shunt and series fields of compound-wound dynamo are, individually, connected for proper polarity, but the connections of the dynamo are so made that they oppose, or buck, each other. **Remedy:** Change polarity of either field; but do not change the connections of both, since the same trouble will then occur again.

Trouble (i): Dynamo runs backwards. **Cause:** Prime mover is running in the wrong direction. **Remedy:** Reverse direction of rotation of prime mover. Or, change the polarity of dynamo by changing the connections of the field of a shunt-wound or series-wound dynamo, or change the connections of the field only of a compound-wound dynamo. Never cross the driving belt, unless it is absolutely necessary.

(**2**) **Symptom:** Voltage too high. **Trouble** (a): Speed of prime mover too great. **Cause:** Speed of prime mover too great. **Remedy:** Reduce speed of prime mover, and adjust governor so the speed will remain constant at a given load. **Trouble** (b): Field too strong. **Cause:** Not enough resistance in series with the field. **Remedy:** By means of a rheostat, cut more resistance into series with the field.

(**3**) **Symptom:** Voltage too low. **Trouble** (a): Speed of dynamo too low. **Cause:** Speed of prime mover too low. **Remedy:** Increase speed of prime mover. Or, either increase size of driving pulley or reduce size of driven pulley. **Trouble** (b): Field too weak. **Cause:** Too much resistance in series with the field. **Remedy:** Cut out some of the resistance, with the rheostat. **Trouble** (c): Load on dynamo too great. **Cause:** Too

many lamps or motors on dynamo circuit. **Remedy:** Reduce the load.

CARE AND MAINTENANCE OF INDUCTION MOTORS

116. Inspection, Care, Repairs, etc.—In order to obtain the best results, motors should be inspected methodically and carefully at regular intervals. In addition to a daily inspection, they should receive a special inspection weekly, monthly, every four months, and yearly. The character of the inspection, and the subsequent treatment advised, differs for each period, and may also vary somewhat in different plants. The following outline of the inspector's duties has been found to work well.

117. Daily.—*Bearings:* Oil bearings, if necessary; see that rings are working; feel bearings for rise in temperature. *Motor frame:* Examine ground wire. *Motor windings:* Feel windings for excess heating. *Rotor:* See if there is proper end play. *Starter:* If starter is situated in a damp place, feel the oil tank; if it feels hot, this denotes the presence of water in the oil.

118. Weekly.—*Bearings:* Examine oil, which renew if found to be gritty or darker in color than usual. *Motor frame:* Adjust end bells to center the rotor. *Motor windings:* If motor is in a dusty place, blow out winding with compressed air or hand bellows. *Rotor:* Use feeler between rotor and stator to ascertain whether or not the rotor is out of center. *Starter:* If motor is started and stopped frequently, overhaul the starter. *Switches and fuses:* Inspect; clean if necessary.

119. Monthly.—*Bearings:* Renew oil on all high-speed motors, and on all that are situated in dusty places. *Starter:* Overhaul starter. *Switches and fuses:* Inspect and clean.

120. Four-Monthly.—*Bearings:* Bearings should be drained and cleaned, and the oil should be renewed. High-speed sleeve bearings should be carefully examined, and in most cases renewed. Ball bearings should be cleaned and greased. *Motor windings:* If windings are subjected to corrosive influences, the motor should be thoroughly cleaned and baked; the windings should be re-varnished, and again baked. *Rotor:* Rotor should be cleaned; if it is a wound rotor, it should be treated the same as the stator.

121. Yearly.—*Bearings:* Renew all bearings. *Motor frame:* Frame should be cleaned with kerosene. *Motor windings:* All windings should be cleaned, varnished, and baked. *Rotor:* Overhaul rotor. *Starter:* Oil should be changed in all starters. *Switches and fuses:* Switches and fuse contacts should be renewed, if badly pitted.

TRANSFORMER TROUBLES

122. Causes of Transformer Troubles and Their Remedies.—Following the same plan that was used for describing the troubles of dynamos and motors, the symptoms, troubles, causes, and remedies of transformers will now be discussed.

(1) **Symptom:** Temperature rises to danger point on oil-cooled transformer.

Trouble (a): Overload. **Cause:** Overload, or low power factor. **Remedy:** Reduce load or increase the power factor of the system. A 100-kw. transformer at 80% power factor is fully loaded at 80 kw.

Trouble (b): Not sufficient oil in tank. **Cause:** Due either to leaky tank, which will be readily noticed, or to insufficient oil when transformer was installed. **Remedy:** Add more oil; weld defective part of tank. (The core and coils should be fully immersed in oil.)

Trouble (c): Oil jellied. **Cause:** Excessive heat; this may roast the windings and ruin the insulation. **Remedy:** If insulation is not damaged, flush the tank with new oil until all the old oil is removed; then refill tank with fresh oil.

(2) **Symptom:** Temperature rises to danger point on air-cooled transformer.

Trouble (a): Overload. **Cause and remedy:** Same as for Trouble (*a*), Symptom (1).

Trouble (b): Not enough volume of air. **Cause:** Blower speed lowered, or air ducts are clogged. **Remedy:** Speed up blower; clean out air ducts. (Care must be exercised in cleaning air ducts. If compressed air be used, do not impress full voltage on windings immediately after, as there is always more or less moisture in compressed air. Half voltage should be impressed on the low-tension windings, and the high-tension windings short circuited. A transformer thus treated may be put back into service in about 5 hours.)

(3) **Symptom**: Temperature rises to danger point on water-cooled transformer.

Trouble: Overload. **Cause and remedy**: Same as for Trouble (*a*), Symptom (1).

Trouble (b): Not enough water flowing through cooling coils. **Cause**: Pressure low, or some obstruction in pipes. **Remedy**: Increase rate of water flow.

Trouble (c): Oil level below cooling coils. **Cause**: Oil leakage around the water inlet. **Remedy**: Stop the leak; then fill the tank with fresh oil; when the tank has been filled, the oil should fully immerse cooling coils.

Trouble (d): No water flowing through cooling coils. **Cause**: Cooling coils plugged. **Remedy**: Remove obstruction, using water or air pressure up to 250 pounds per square inch. If the water contain lime or other impurities, the cooling coils should be cleaned at least as often as every 6 months with a solution of equal parts of pure water and hydrochloric acid. This solution should be allowed to stand for not more than 1 hour, so that the acid will not attack the coils, and the coils should then be flushed with clean water.

Trouble (e): Oil saponified on outside of cooling coils. **Cause**: Transformers operated at too low a temperature. **Remedy**: If oil does not soften by overheating, the cooling coils should be removed and scraped.

(4) **Symptom**: In addition to above symptoms, explosions occur in transformer tank. **Trouble (a)**: Short circuit between adjacent layers of high-tension windings. **Cause (1)**: Moisture in oil (or in air, in the case of an air-cooled transformer). Moisture in oil may be due to a leak in the cooling coil, or to "breathing." All transformers breathe; that is, air is forced in and out alternately because of changes in temperature. **Remedy**: Test for moisture in oil in either of two ways. *First*, measure the break-down voltage required to force a spark through a gap between two 1-inch disks immersed in the oil; oil that is free from moisture should stand a break-down test of 25,000 volts when the disks are 0.1 inch apart. *Second*, when the apparatus just mentioned is not available, heat a few crystals of copper sulphate $CuSO_4$ (blue vitriol) on a hot plate until the crystals turn white. Take a small bottle and fill it with oil from the bottom of the transformer tank (this is where the moisture will collect), drop a few grains of the heated copper sulphate in the oil, and shake well.

If there be any moisture whatever in the oil, the solution will turn blue; if there be no moisture present, the solution will retain its natural color. (When taking a sample of the oil, it is best to use a long glass tube. Place thumb over one end of tube, and insert tube in oil, with open end extending to the bottom; then remove thumb; and allow tube to fill. Again place thumb over end of tube, and withdraw tube.) If the test shows that the oil contains moisture, pass the oil through a filter press. After all the oil has been taken out, the tank should be flushed with clean oil. The oil can be replaced in the tank as soon as it is filtered, and the transformer can immediately be put back into service. (Before testing the oil for moisture, the transformer can be cut out of service, and the service can be resumed on open delta, if delta connected. If star connected, see Art. **125**, all transformers in the bank become inoperative.) **Cause** (**2**): Insulation broken down; insulation punctured, due to line surges. **Remedy**: Replace sections of winding causing the trouble. **Cause** (**3**): Shifting of coils, due to switching on and off of heavy loads. **Remedy**: Same as for Cause (2). **Cause** (**4**): Not enough insulation on the end turns. (End turns should have from 2 to 5 times greater insulation than the inside turns.) **Remedy**: Same as for Cause (2), and re-insulate end turns to proper thickness. **Cause** (**5**): Electromagnetic stresses too great, due to improper core construction. **Remedy**: Send transformer to factory to be re-designed; this trouble will seldom be encountered. **Cause** (**6**): Transformer coils not properly baked before assembling. **Remedy**: Short circuit primary, or high-voltage, windings, and impress about half voltage on low-tension windings. **Cause** (**7**): Lightning discharge without protection. **Remedy**: Repair damaged coils, or replace with new coils. (All transformers should be protected by having choke coils or reactors in series with them.) **Cause** (**8**): Oscillating currents caused by conductors swinging together, due to wind storms. **Remedy**: Same as for Cause (2). **Cause** (**9**): Unstable voltage; generator voltage not steady. **Remedy**: Replace the sections of the winding that cause this trouble. **Cause** (**10**): Insulation is roasted by constant overload. **Remedy**: Replace the sections of the winding that cause this trouble.

Trouble (**b**): Short circuit between high-tension and low-tension windings. **Cause**: Any of the causes in Trouble (**a**). **Remedy**: Replace the sections of the winding that cause this trouble.

Trouble (c): Ground between low-voltage winding and core. **Cause:** Lightning discharge; insulation breakdown, due to line surges or to shifting of coils. **Remedy:** Same as for Cause (7), Trouble (a).

Trouble (d): Short circuit on terminal board. **Cause:** Moisture in oil. **Remedy:** Remove terminal board; bake and varnish, and pass oil through filter press.

Trouble (e): Short circuit between high-tension and low-tension bushings. **Cause:** Bushings broken or cracked. **Remedy:** Replace bushings.

Trouble (f): Improper division of load. **Cause:** Parallel operation of transformers that have different characteristics. **Remedy:** Transformers that are to be paralleled should have the same characteristics. If one bank has a high reactance, and it is desired to parallel it with a bank having a low, or no, reactance, reactance coils should be inserted between the two banks.

Trouble (g): Low-voltage windings punctured. **Cause:** Ground on high-voltage line of a star-delta system. A ground on such a system imposes delta voltage on the star winding, or star voltage $\times \sqrt{3}$, and the bank cannot be operated. **Remedy:** Remove ground before trying to operate. If the system is properly protected, the circuit breakers will open, and they cannot again be closed.

(5) **Symptom:** Unequal heating in bank of star-connected transformers, with the neutral grounded. **Trouble:** Ground on one phase. **Cause:** Defective insulation in transformer; or ground on the line, due to defective insulators, dead birds, kite strings, or other obstructions. **Remedy:** Immediately disconnect the bank from service, since a trouble of this kind short circuits the bank. (The insulation between the windings and the core is limited to a voltage of 57.7% of the line voltage, with a star connection; and if one phase or the line is grounded, the voltage between the group and the remaining two circuits is increased to as high as full voltage, in some cases.)

(6) **Symptom:** Unequal heating in bank of transformers, connected star primary, delta secondary, with neutral grounded on high-voltage side. **Trouble:** Ground on one of the primary phases. **Cause:** Same as for Symptom (5). **Remedy:** Disconnect the bank until trouble is removed, since the bank cannot be operated on open delta.

(7) **Symptom**: Voltage not the same in all phases of a three-phase bank of transformers. **Trouble (a)**: Ground on one phase of a bank connected star-delta. **Cause**: Broken insulator on line; line in contact with some obstruction leading to ground; defective insulation in transformer; bushing punctured, and terminal grounded. **Remedy**: Cut out bank in which defect occurs, and remedy by removing cause of ground; replace insulators, bushings, or section of winding causing the trouble. **Trouble (b)**: One transformer bucking the other two. **Cause**: One transformer so connected that its polarity is opposite that of the other two; if not cleared soon, one or more of the transformers may burn out. **Remedy**: Change the polarity of the transformer causing the trouble. To test polarity, connect the primaries in parallel, and connect the secondaries in parallel, with a fuse in series with the secondary windings. If transformers are of opposite polarity, the fuse will short circuit one transformer on the other, and will consequently blow the fuse. If the fuse blows, interchange the leads, and test until fuse does not blow; the polarities will then be the same.

(8) **Symptom**: Voltage too low. **Trouble**: Wrong ratio. **Cause**: Leads not connected to proper taps. **Remedy**: Raise the taps to one higher, or until voltage is correct.

(9) **Symptom**: Voltage too high. **Trouble**: Wrong ratio. **Cause (1)**: Same as for Symptom (8). **Remedy**: Lower taps until voltage is correct. **Cause (2)**: Transformers having different ratios are connected in parallel. **Remedy**: Change ratios until all transformers are the same; if this cannot be done, replace transformers.

COMPENSATOR TROUBLES

123. Starting Compensators.—It was stated in *Elements of Electricity*, Part 2, Vol. II, that the chief use of autotransformers was for starting alternating-current motors, where a low voltage is required to start and while running up to speed; in such cases, they are called *starting compensators* or, more simply, *compensators*. The troubles, together with their symptoms, causes, and remedies, are detailed herewith.

(1) **Symptom**: Motor will not start, although it is known there is nothing wrong with the motor itself. **Trouble (a)**: Motor cannot develop sufficient torque. **Cause**: Voltage too low.

Remedy: Raise the taps on compensator to next higher, or even more if necessary. **Trouble** (b): Motor trying to run single phase. **Cause:** One fuse blown, or open circuit in one overload relay. **Remedy:** Replace fuse. Replace open-circuited relay, which is liable to be burned out.

(2) **Symptom:** Motor starts too quickly. **Trouble:** Motor developing too much torque. **Cause** (1): Taps too high. **Remedy:** Lower taps. **Cause** (2): One or more compensator coils are short-circuited. **Remedy:** Replace coil or coils with new ones.

(3) **Symptom:** Compensator issues a buzzing sound. **Trouble** (a): Laminations loose. **Cause:** Vibration, or rough handling. **Remedy:** Tighten bolts holding lamination framework; or, wedge between coil and laminations. **Trouble** (b): Grounds. **Cause:** Moisture, or rough handling. **Remedy:** Insulate coil from ground, or, in most cases, insert a new coil.

(4) **Symptom:** A peculiar rumbling noise issues from compensator oil tank. **Trouble:** Contacts arcing. **Cause:** Contacts making poor connection. **Remedy:** Clean and polish contacts, and press them together; or, renew contacts, if badly pitted.

(5) **Symptom:** Heating of oil tank. **Trouble:** Water in oil. **Cause:** Water in oil. **Remedy:** Change oil as soon as noticed. (If oil is not changed, the compensator coils will soon burn out, as the water provides a path for the current, even when the coils are cut out of the circuit.)

(6) **Symptom:** Explosions occur in starter, with the result that flames and smoke issue from the case. (One or more fuses will usually blow when this occurs.) **Trouble** (a): Contacts arcing. **Cause:** Loose contacts. **Remedy:** Repair or replace contacts.

Trouble (b): Switch mechanism or contacts grounded. **Cause:** Water in oil and mechanism. **Remedy:** Locate ground, which will usually be denoted by the charred appearance of the fiber on the operating bars. Either re-insulate the bar or replace with a new one.

Trouble (c): Short circuit between contacts. **Cause:** Caused, in the first place, by water in the oil; this makes a path for the current, which, in time, will heat and carbonize the contact bar, whether made of wood or of fiber-covered steel. **Remedy:** Scrape out all traces of carbon; or re-insulate, if of fiber; or renew, if necessary. If operating bar is of wood, scraping out the carbon and revarnishing the bar is usually all that is necessary. (It is

best to renew the oil in the case of all three of the foregoing troubles.)

(7) **Symptom:** The plunger of the no-voltage coil does not operate. **Trouble:** The no-voltage coil is burned out, or it is disconnected. **Cause:** Moisture, or rough handling. (If the plunger or core of a no-voltage coil is removed, the coil will soon burn out.) **Remedy:** Repair broken connections, or replace burned-out coil.

(8) **Symptom:** Handle of starter does not stay in running position, even when motor is not overloaded. **Trouble (a):** Hammering of plunger of no-voltage coil. **Cause:** Loose contact between overload and no-voltage relays. **Remedy:** Adjust contacts.

Trouble (b): The overload relays are set too low. **Cause:** (1) Plunger of overload relay is stuck or shifted. **Remedy:** Either adjust overload or time setting. (2) Oil in dashpots too thin. **Remedy:** Use a thicker grade of oil.

124. Care of Starting Compensators.—Starters should be thoroughly inspected at least once a month. In those cases where a motor is started and stopped frequently, the starter should be inspected every two weeks.

125. Star and Delta Connections.—The phrases *star connection* and *delta connection* refer to the connections of the windings on a

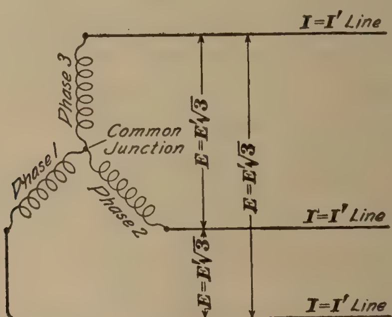

FIG. 39.

three-phase alternator. The **star connection** is shown in Fig. 39, and it will be noted that each winding has one end connected to a common junction point. Letting E = the voltage across the lines, and E' = the voltage per phase, $E = E'\sqrt{3}$. The

current, however, for each line is the same as the current per phase. This connection is also sometimes called a Y connection.

The **delta connection,** also called the **mesh connection,** is shown in Fig. 40; it derives its name from its triangular shape, which resembles the Greek capital letter delta Δ. The three windings here form a closed circuit; the voltage across the lines is the same as the voltage per phase; but the current in each line

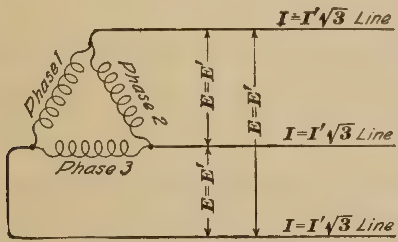

FIG. 40.

is equal to the current per phase times the square root of 3, *i.e.*, $I = I'\sqrt{3}$, I being the current in each line, and I' the current per phase.

The power in kilovolt-amperes is, letting f = the power factor,

$$P = \sqrt{3}EIf,$$

for either connection.

125A. Transformer Connections.—Practically all modern power installations are three-phase. Although, in Europe, three-phase transformers are much favored, in Canada and America, single-phase units are almost invariably used, *i.e.*, a transformer for each phase. These are connected in star or delta, as the conditions of their application require.

It may here be noted that when single-phase transformers are used, if one transformer on a three-phase circuit breaks down, it is still possible to continue operating on the other two; this is known as the **open-delta** connection. It is not to be considered as a permanent operating connection, because it will deliver only 87% of rated capacity, and it is liable to cause disturbances on transmission lines by reason of unbalancing. However, the open-delta connection is extremely useful in an emergency, and the connection should be regarded strictly in that light.

In the case of three-phase transformers, if one phase breaks down, it is usually impossible to continue operation; in any case,

a break-down in a three-phase unit necessitates a complete shut-down of that unit for effecting repairs.

It is important to safeguard transformers from the dangers due to continuous heavy overloads and consequent overheating. Continually overloading a transformer results in "sludging" of the oil; this means that the oil is decomposed, and a precipitate is thrown down, filling the ducts and covering the core and coils with a heat-insulating mud. The cooling of the transformer becomes defective under these conditions; this causes the transformer to overheat, and a cumulative process is set up, resulting in the precipitation of more sludge and still further overheating. The result is a break-down and serious expenditure for repairs.

All power transformers should be fitted with thermometers having scales easily read by attendants, and the temperatures and loads should be subject to careful daily observation.

GENERAL MILL EQUIPMENT

(PART 2)

EXAMINATION QUESTIONS

(1) (*a*) What are interpoles? (*b*) Why and on what kind of electrical machines are they used?

(2) (*a*) What is a kilovolt-ampere? (*b*) Why is this unit frequently employed instead of the kilowatt?

(3) Explain fully how a low-power factor causes trouble and loss.

(4) (*a*) What general type of motor is particularly adapted to use in pulp mills? (*b*) in paper mills? (*c*) Mention the advantages of squirrel-cage induction motors.

(5) (*a*) What are the two distinctive uses of synchronous motors? (*b*) Mention some of their advantages and disadvantages.

(6) Give several reasons for the use of electric steam boilers.

(7) For what purposes are direct-current motors adapted in paper mills, and why?

(8) What are the three principal considerations governing the laying out of a motor drive? Discuss them.

(9) Discuss briefly direct drives as compared with other types of drives.

(10) An induction motor is observed to be running hot, and explosions occur in the windings; what is the trouble, what causes it, and how may it be remedied?

(11) A wound-rotor motor turns at about half speed; what causes this, what is the trouble, and how may it be remedied?

(12) A synchronous motor starts, but it fails to come up to speed. Diagnose the trouble and the cause, and prescribe the remedy.

(13) Name some (at least six) of the causes that make the brushes of a direct-current generator spark: state the troubles that result from them, and their remedies.

(14) A shunt-wound motor runs too fast; what is the matter, and why, and what should be done about it?

(15) A direct-current motor runs backward; what causes this, and how can the trouble be remedied?

(16) Describe the method for testing oil for moisture by the use of copper sulphate.

SECTION 6

GENERAL MILL EQUIPMENT

(PART 3)

BY J. O. ROSS

HEATING AND VENTILATION

GENERAL PRINCIPLES

HEATING

126. Why Heating is Necessary.—The heating and the ventilation of the paper mill are so closely related as really to constitute a single subject. In some departments, the heating is the important factor, while in other departments, the ventilation is the primary object. In almost every department, however, there is a demand for both heating and ventilation.

A building is required to be heated in order to offset two sources of loss; first, the transmission of heat through the roof, walls, doors, windows, and floors; second, the leakage outwards of the warm air of the building, and the leakage inwards of the cold outside air through doors, cracks, and other places where the outside air can enter the building.

127. Loss of Heat by Radiation.—The first source of loss of heat, i.e., the transmission of heat through the material of which the building is constructed, is directly proportional to the difference in temperature between the outside and the inside of the building, and by the rate of transmission of heat through the material of the building, or, in other words, by the *thermal*

conductivity of the material (see *Physics*, Part 2, Vol. I). This loss of heat, which is called the **radiation loss,** is due entirely to the passage of heat through the building material from the *inside* to the outside of the building.

128. Loss of Heat by Leakage.—The second source of loss of heat is by leakage through cracks, around and through doors, windows, etc. The amount of heat thus lost is very seldom realized; but, it is safe to state that there will be sufficient leakage to change the entire volume of air in an ordinary building once every hour. It does not matter whether this is leakage inwards of cold air or leakage outwards of warm air, the final result is the same. It ultimately means that a volume of air equal to the volume of air in the building must be heated from the temperature outside to the temperature (average) that is maintained inside the building. In many of the departments of the paper mill, this amount will be greatly exceeded; for instance, it will be readily perceived that in the case of a finishing room, which has open doors into the machine room, a very large draft of air passes from the finishing room into the machine room, and this must be replaced by leakage inwards of cold air. This should be very carefully borne in mind, and sufficient heat must be allowed for in addition to the radiation loss to take care of the leakage loss.

129. Heat Loss in British Thermal Units.—In calculating heat losses, it will be apparent at once that only approximate results can be obtained; at the same time, the final result will be sufficiently accurate for all practical purposes if the computation be performed intelligently. It will therefore be sufficiently exact to define a British thermal unit (1 B.t.u.) as the amount of heat required to raise the temperature of 1 pound of water 1°F., regardless of its temperature; hence, to raise the temperature of 25 pounds of water (at any temperature) 15°, will require $25 \times 15 = 375$ B.t.u. Similarly, the pressure of the air both inside and outside is assumed to be constant. The specific heat of air at constant pressure is 0.241 (see *Physics*, Part 2, Vol. I); hence, it will take 0.241 B.t.u. to raise the temperature of 1 pound of air 1°F.; or, 1 B.t.u. will raise $\frac{1}{0.241} = 4.15$ pounds of air 1°F. in temperature.

130. Radiation Loss in B.t.u.—To compute the radiation loss in heat units, use is made of the constants given in Table I. The

TABLE I

Material	k	Material	k
Brick wall—4″ thick	0.66	Single wooden floor 1″ thick, with lath and plaster ceiling beneath	0.27
Brick wall—8″ thick	0.46	Single floor without ceiling beneath	0.46
Brick wall—12″ thick	0.32	Double floor with lath and plaster ceiling beneath	0.18
Brick wall—16″ thick	0.26	Double floor without lath and plaster ceiling beneath	0.31
Brick wall—20″ thick	0.23	Dirt floor—no covering	0.23
Brick wall—24″ thick	0.19	Concrete on dirt (assume ground temperature as 30°)	0.23
Brick wall—28″ thick	0.17	Wood floor on dirt	0.14
Brick wall—32″ thick	0.14	Galvanized-iron siding	1.21
Brick wall—36″ thick	0.13	Book tile roof	0.80
Brick wall—40″ thick	0.11	Slate roof	0.80
Concrete or stone—12″ thick	0.49	2″ plank	0.40
Concrete or stone—16″ thick	0.43	8″ brick wall lined with 4″ terra cotta blocks—plastered inside	0.22
Concrete or stone—20″ thick	0.38	12″ brick wall lined with 4″ terra cotta blocks—plastered inside	0.18
Concrete or stone—24″ thick	0.35	16″ brick wall lined with 4″ terra cotta blocks—plastered inside	0.16
Single window or skylight[1]	1.22	8″ brick wall lined with 4″ hollow gypsum blocks—plastered inside	0.20
Double window or skylight[1] independent sashes	0.57	12″ brick wall lined with 4″ hollow gypsum blocks—plastered inside	0.17
Vault light[1]	1.43	16″ brick wall lined with 4″ hollow gypsum blocks—plastered inside	0.15
Door—close fitting, not often open	0.57	4″ terra cotta roof—plastered	0.42
Door, average (same as glass)	1.22	8″ terra cotta roof—plastered	0.26
Sidewalk light	1.50	12″ terra cotta roof—plastered	0.20
Hyrib construction	1.00	Lath and plaster on studding	0.60
5-ply tar and gravel roofing on 3″ plank	0.30		
5-ply tar and gravel roof on 4″ reinforced concrete slab	0.64		
Frame walls, clapboard, studding, and plaster	0.45		
Frame walls, clapboard, paper, studding, and plaster	0.31		
Frame walls, clapboard, sheathing, studding, and plaster	0.29		
Frame walls, clapboard, paper, sheathing, studding, and plaster	0.24		

[1] In all cases, measure the full opening for glass area or door area.

values of k in this table are the number of heat units (B.t.u.) that will pass through 1 square foot of the materials specified in 1 *hour*, for a difference of temperature between two sides of the material of 1°F. For example, if the area of a 16-inch brick wall is 1440 square feet, and there is a difference of temperature between the inside and outside of this wall of 36°F., the radiation loss in 5 hours and 20 minutes will be

$$U = kah(t_1 - t_0) = 0.26 \times 1440 \times 5\tfrac{1}{3} \times 36 = 71{,}885 \text{ B.t.u.}$$

In this formula, t_1 is the temperature of the inside air, t_0 is the temperature of the outside air, a is the area of the wall or other surface, h is the number of hours, k is the constant from Table I, and U is the radiation loss in B.t.u. Since the constant is given

to only two significant figures and is subject to considerable variation, the heat loss in this case, may be taken as 72,000 B.t.u.

It should be noted that the values obtained by the use of these constants are for still air; if heavy winds blow on the outside of the wall, there is a considerable increase in the loss of heat. For a severe northern exposure, it is common to allow $33\frac{1}{3}\%$ in addition to the calculated amount; for an eastern exposure, 15% additional should be allowed. For a high-pitched roof, where the wind will blow severely on the roof, it is well to add about 20% to the computed radiation for the entire roof.

In the case of interior floors, there is, in general, very little transmission of heat, since the under side of the floor and the upper side are usually of the same temperature. For a concrete floor laid directly on the ground, it may be assumed that the temperature of the ground is 30°F.; therefore, the difference in temperature between the two sides of the floor is the difference between the temperature inside the building and 30°. In this connection, however, it is well to remember that many concrete floors which are apparently laid on the ground have a clear space underneath them, and that they are almost as cold underneath as the outdoor atmosphere.

131. The Total Loss of Heat.—When the losses through all the walls, windows, roofs, etc. have been calculated, and the transmission rate per hour has been secured, corrected by proper additions for undue exposure and wind, the result will be the number of heat units lost per hour by radiation. To this must be added the loss due to leakage, and the sum will be the total loss.

Assuming an ordinary building, the amount of heat lost through leakage per hour will be the amount of heat required to raise the temperature of a volume of air equal to the volume of the entire building from the outside temperature to the inside temperature. Suppose the internal volume of the building to be 1,500,000 cubic feet; then there will be an inward flow of 1,500,000 cubic feet of cold air every hour. If it be supposed, further, that the outside temperature is 0°F., and that the average temperature inside is to be maintained at 70°, then sufficient heat must be supplied to raise the temperature of 1,500,000 cubic feet of air from 0° to 70°. The number of heat units required to effect this may be roughly estimated as follows:

The specific volume (volume occupied by 1 pound) of air varies directly with the absolute temperature. For a tempera-

ture of 70°F., the volume occupied by 1 pound may be calculated by the following formula (see *Physics*, Part 2, Vol. 1), in which p = the absolute pressure (14.7 pounds per square inch in this case), v = the volume in cubic feet, and T = the absolute temperature = 459.4 + 70 = 529.4° in this case:

$$pv = 0.37051T$$

Solving for v,

$$v = \frac{0.37051T}{p} = \frac{0.37051 \times 529.4}{14.7} = 13.34 \text{ cu. ft.}$$

Since 1 B.t.u. will raise the temperature of 4.15 pounds of air 1°F. (see Art. **129**), it will raise the temperature of 13.34 × 4.15 = 55.36 cubic feet 1°F. when the temperature of the air is 70°. The volume will be quite a little less than this at 0°; but for practical purposes, it may be assumed that 1 B.t.u. will raise the temperature of 55 cubic feet of air 1°F. Another reason for assuming such a comparatively high value is that atmospheric air always contains moisture, and the specific weight (weight per cubic foot) of moisture-laden air is less than that of dry air; consequently, the volume per pound of moist air is greater than that of dry air. For all calculations pertaining to commercial heating of buildings, therefore, it will be a sufficiently close approximation to assume that 55 cubic feet of air will be heated 1°F. by the application of 1 B.t.u. of heat.

It was previously assumed that 1,500,000 cubic feet of air was to be heated from 0° to 70°; hence, the total number of heat units per hour required to effect this is $\frac{1500000 \times 70}{55} = 1{,}910{,}000$ B.t.u. per hour, which is the number of heat units per hour required on account of leakage. To this must be added the radiation loss, and the sum will be the total heat that must be supplied by the heating system every hour. Assuming that the radiation loss has been found to be 1,090,000 B.t.u. per hour, the total heat to be supplied by the heating system is 1,910,000 + 1,090,000 = 3,000,000 B.t.u. per hour.

132. Heating by Direct Radiation.—If the building is to be heated by steam coils, this is called heating by **direct radiation**; and the coils must have sufficient radiating surface to transmit 3,000,000 B.t.u. per hour to the surrounding air. The radiating surface is that part of the outside area of the coils that comes in contact with the air; and when low-pressure or exhaust steam is used, it is customary to assume that 1 square foot of radiating

surface will transmit 250 B.t.u. per hour. Consequently, to transmit 3,000,000 B.t.u. per hour will require 3,000,000 ÷ 250 = 12,000 square feet of radiating surface

The steam in the coils is assumed to be dry and saturated (see *Physics*, Part 2, Vol. I); hence, if it gives up any heat, as by radiation, it must condense. In condensing, it gives up its latent heat of evaporation, but still maintains its temperature, and it is this latent heat of evaporation that heats the air. Assuming that the pressure of the steam in the coils is 5 pounds per square inch, gauge, the latent heat of evaporation is 960.6 B.t.u. (see Table IV at end of Vol. III); but, for practical purposes in connection with commercial heating problems, this may be taken as 1000 B.t.u. Therefore, the number of pounds of steam that must be supplied per hour is 3,000,000 ÷ 1000 = 3000 pounds per hour.

133. The Fan System of Heating.—Should it be desired to heat this building by a fan system, which is becoming the more

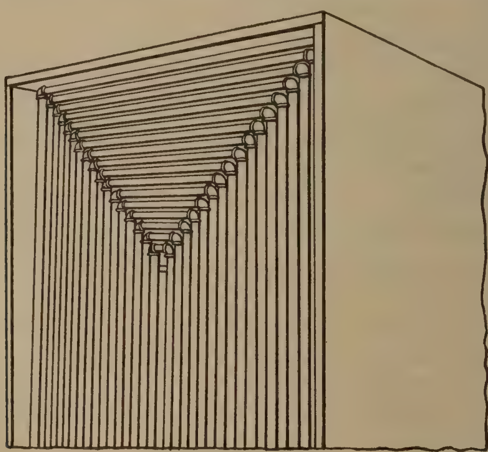

Fig. 41.

common method of heating paper-mill buildings, the air used must carry to the building 3,000,000 B.t.u. every hour. If ventilation is not required, except for the natural leakage before mentioned, the air may be re-circulated through the building. **Re-circulating** the air means taking the air that is in the building at, say, 70°F., heating it, and discharging it back into the building at a higher temperature. Unless special ventilation is required, this system is entirely satisfactory.

The usual fan system consists of a fan drawing air through a bank of steam coils, similar to that shown in Fig. 41, which heat the air. The area of the steam coils is determined by the increase in temperature of the air passing through the coils. It will at once be evident that the effective heat possessed by this air as it enters the building is the amount it gives up in cooling from the temperature at which it enters to the average temperature of the building. If the building be maintained at an average of 70° and the air enters at 100°, the heat supplied to the room is the heat obtained by the cooling of the air from 100° to 70°, i.e., by a fall of temperature of 30°. This difference of temperature is a measure of the amount of heat required to supply 3,000,000 B.t.u. per hour. Since 1 B.t.u. raises the temperature of 55 cubic feet 1°F., the number of cubic feet of air per hour that must be raised 30° in temperature is $\frac{3000000 \times 55}{30} = 5{,}500{,}000$ cubic feet.

If, however, the coils were to heat the air to 130° instead of 100°, the difference in temperature would then be $130 - 70 = 60°$, and only half as much air would need to be supplied by the fan, since $\frac{3000000 \times 55}{60} = 2{,}750{,}000$ cubic feet per hour. It is obvious that the higher the temperature of the air discharged into the room by the fan the less is the quantity of air required, and vice versa.

The proper temperature of the air supplied to the room (which determines the volume of the air), or the proper volume of the air supplied to the room (which determines the temperature), is largely a matter of experience. The more air that is supplied to the room the more it can be distributed around the room, and the more uniform will be the heating results. Further, if it should be desired to supply air for special ventilation purposes, the volume then required may be the quantity that determines how much air should be furnished. The ventilation and heating of the machine room will not now be considered, because it constitutes a problem that is so radically different from that applying to the other departments as to necessitate consideration by itself.

Under ordinary conditions, where heating alone is required, such as for the finishing room, stone storage, shipping rooms, warehouses, machine shops, decker rooms, etc., it will usually be

sufficient to supply air to the extent of three times the volume of the room every hour. Assuming, for the present, that this also applies to the machine room, the total amount of air to be supplied to the building is $1500000 \times 3 = 4{,}500{,}000$ cubic feet per hour; and since this must give up 3,000,000 B.t.u., the temperature of this air must be $\frac{3000000 \times 55}{4500000} = 37°$ higher than the average temperature of the building; that is, the temperature of the entering air from the fan must be $70 + 37 = 107°$. The number of heat units required to heat this air is $\frac{4500000 \times 37}{55}$ $= 3{,}030{,}000$, and the amount of steam required is $3030000 \div 1000 = 3030$ pounds of steam per hour, a result that is practically the same as that previously obtained for direct radiation.

VENTILATION

134. Air and Heat for Ventilation.—Thus far, only the air required for heating has been considered, the air moved by the fan being only that necessary to heat the building, and being obtained from the building itself by re-circulating it.

Suppose, now, that it were desired to ventilate as well as to heat; then fresh air must flow through the heating coils and be discharged into the building by the fan, the amount of this fresh air being equal to the amount required for ventilation. From the circumstances of the case, it may be decided that 20,000 cubic feet per minute, or $20000 \times 60 = 1{,}200{,}000$ cubic feet per hour, is required for this purpose, in addition to the air lost by ordinary leakage.

In Art. **133**, it was assumed that 4,500,000 cubic feet of air per hour was to be circulated by the fan; this same amount of air will still be circulated, but instead of being all obtained from the room at a temperature of 70°, 1,200,000 cubic feet of air will be obtained from outside at a temperature of, say, 0°. It will, of course, require extra steam to heat this outside air to the temperature of the air inside the building, the amount so required being $\frac{1200000 \times (70 - 0)}{55 \times 1000} = 1527$ pounds of steam per hour. The total steam required under these conditions would then be $3000 + 1527 = 4527$ pounds per hour, and this would take care of

both the heating and the ventilation. If it were necessary to use still more air for ventilation, the steam requirements would be greater in the same proportion. For instance, extra ventilation is required in beater rooms where the hot water used produces vapor (as in board mills), in grinder rooms, or in any department where moisture, fumes, or dust have to be removed; the machine room is the most striking example of this excessive ventilation requirement.

In many departments, the ventilation is far more important than the heating; here, the ventilation determines almost entirely the amount of air that must be circulated. If no heating is required, all that is necessary is to heat the incoming air to the room temperature.

135. Hot Air vs. Direct Radiation.—There seems to be a general impression that it takes more steam to heat a building by means of a hot-air system, such as a fan system, than it does when steam coils are used; that is, that the radiation system is more economical than the hot-air system. Such, however, is not the case. The prevailing opinion is probably due to the fact that a fan system is almost always used when ventilation is required; and it is at once apparent from what has preceded that the use of cold outside air does take more steam. If heating only is required, then, as previously shown, it is immaterial which system is adopted; the same amount of steam will be required in either case to supply the heat units necessary to offset the radiation and leakage losses, provided the same average temperature is maintained in the building. In fact, for several reasons, the fan system usually requires less steam. For instance, in many cases, the steam coils are strung along the walls. The result is that although the average temperature within the building may be 70°, the temperature between the coils and the wall may be 100°; the loss by radiation will then be proportional to the difference between 100° and the temperature outside, instead of the difference between 70° and the temperature outside, and the steam coils then have to take care of a much greater radiation loss. Another common way of installing the coils is to run them along the ceiling. As a consequence, the heated air rising from these coils gathers near the roof or ceiling; and while the temperature may be 70° near the floor, where the employes are, it may be 100° at the ceiling, and there will be a much greater transmission of heat through the roof or ceiling. The fan system,

on the other hand, distributes hot air through the room, and it is no hotter near the walls or ceiling than in other parts of the room.

136. Measuring Air.—Air may be measured in pounds or in cubic feet, i.e., it may be measured by weight or by volume. In all problems pertaining to heating and ventilation, the pressure of the air may be considered constant, and may be taken as 14.7 pounds per square inch, absolute. With this understood, a given weight of air, say 1 pound, will occupy a volume of a certain number of cubic feet V. The volume, however, varies directly as the absolute temperature T(= 459.4 + the temperature indicated by the thermometer), and may be expressed by the formula

$$V = \frac{0.37051T}{14.7} = 0.025205T.$$

If a pound of cold air be heated, it will occupy a greater volume; if the heated air be cooled to the original temperature, the volume will be exactly the same as before it was heated; and if cooled below the original temperature, the volume will be less than the original volume. But the weight remains the same, 1 pound, and the number of molecules of air is unaltered by the change in volume and temperature.

For this reason, in accurate calculations, the quantity of air handled should be expressed in pounds rather than in cubic feet. As an illustration, consider the ventilation of a machine room. A fan draws in a certain quantity of cold air, at zero say, from outdoors, and it is heated by passing it over a bank of steam coils. This air may be heated to 100°F. and then discharged into the machine room, which may have an average temperature of 80°. After cooling down from 100° to 80°, the air passes under the hood, and may be heated up to 120°, passing from the hood into the atmosphere at that temperature. Suppose the quantity of air handled in a certain time were 1000 pounds. The volume of this air at 0° is 11,580 cubic feet; at 100°, the volume is 13,600 cubic feet; and at 120°, the volume is 14,100 cubic feet; but it is the same 1000 pounds in all three cases. The matter is further complicated by the fact that when the air passes out of the ventilators, it contains water vapor from the machine; this increases the volume, so that this 1000 pounds of air when 75% saturated with moisture (vapor) has a volume of 16,050 cubic feet of mixed air and vapor at 120°.

It is obviously difficult to follow the volume of the air through all the different changes in temperature; but if the quantity of air be expressed in pounds, the number of pounds is the same for all temperatures. It is to be noted, however, that the capacities of fans are always rated in cubic feet per minute, not in pounds per minute, because fans deliver air by volume and not by weight; the case is similar to that of a pump, which delivers a certain number of cubic feet or gallons of liquid per minute, regardless of its specific gravity. If the volume and temperature of the air be known, then the number of pounds of air delivered by the fan can be readily calculated.

137. Capacity of Fan.—Suppose the fan is to discharge 1000 pounds of air per minute. If the fan is to draw in the air at 0° and blow it over the steam coils to heat it, the fan to be selected would have a capacity of 11,580 cubic feet per minute (see Art. **136**). If the air passed through the steam coils and was heated to 100° before entering the fan, a larger fan must be selected, since it would have to discharge 14,100 cubic feet per minute. If an exhaust fan were used to draw the air and vapor from the hood, the air being 75% saturated and the temperature 120°, the fan must then have a capacity of 16,050 cubic feet per minute. Yet, in all three cases, the weight o the a r is the same, 1000 pounds per minute. Therefore, in selecting a fan for specific duty, it is necessary to determine the volume discharged at the temperature at which the air enters the fan.

138. Heat Required to Heat the Air.—The amount of heat required to heat the air is directly proportional to the *weight* of the air; it is not determined by the volume of the air. Consequently, if the amount of steam required to heat a certain quantity of air is to be determined accurately, it is first necessary to find the weight of the air. Since all instruments used for measuring air give the result in cubic feet per minute, this must be changed into pounds when more exact results are desired.

In Table II, the second and eighth columns, which are headed 0%, give the specific volumes of *dry air* corresponding to the temperatures in the first and seventh columns, which range from 70°F. to 131°F. Knowing the temperature, find from the table the number of cubic feet one pound will occupy at that temperature; then the volume as measured, divided by the value obtained from the table will be the weight of the air. Thus, to find the weight

TABLE II

Temp. (Fah.)	Volume of 1 pound of air in cubic feet for humidity of:					Temp. (Fah.)	Volume of 1 pound of air in cubic feet for humidity of:				
	0%	25%	50%	75%	100%		0%	25%	50%	75%	100%
70°	13.34	13.44	13.52	13.61	13.69	101°	14.12	14.37	14.62	14.87	15.11
71°	13.37	13.47	13.56	13.65	13.73	102°	14.15	14.40	14.66	14.91	15.17
72°	13.39	13.49	13.59	13.68	13.77	103°	14.17	14.43	14.70	14.96	15.23
73°	13.42	13.52	13.62	13.72	13.81	104°	14.20	14.47	14.75	15.02	15.30
74°	13.44	13.55	13.65	13.75	13.84	105°	14.22	14.51	14.79	15.07	15.36
75°	13.47	13.58	13.68	13.78	13.88	106°	14.25	14.54	14.84	15.13	15.43
76°	13.49	13.61	13.71	13.82	13.92	107°	14.28	14.58	14.89	15.19	15.50
77°	13.52	13.64	13.75	13.86	13.97	108°	14.30	14.61	14.93	15.25	15.56
78°	13.55	13.67	13.78	13.90	14.01	109°	14.33	14.65	14.98	15.31	15.63
79°	13.57	13.70	13.82	13.93	14.05	110°	14.35	14.68	15.03	15.37	15.70
80°	13.60	13.72	13.85	13.96	14.09	111°	14.38	14.72	15.07	15.42	15.77
81°	13.62	13.75	13.88	14.00	14.13	112°	14.40	14.75	15.11	15.48	15.84
82°	13.65	13.78	13.91	14.04	14.18	113°	14.43	14.79	15.17	15.54	15.92
83°	13.67	13.81	13.95	14.08	14.22	114°	14.45	14.83	15.22	15.61	16.00
84°	13.70	13.85	13.99	14.12	14.26	115°	14.48	14.87	15.27	15.67	16.08
85°	13.72	13.88	14.02	14.16	14.31	116°	14.50	14.91	15.32	15.73	16.17
86°	13.75	13.91	14.06	14.21	14.36	117°	14.52	14.95	15.38	15.80	16.25
87°	13.77	13.94	14.09	14.25	14.40	118°	14.55	14.99	15.43	15.87	16.33
88°	13.80	13.97	14.13	14.29	14.45	119°	14.58	15.03	15.49	15.95	16.42
89°	13.82	14.00	14.17	14.33	14.50	120°	14.60	15.07	15.55	16.02	16.50
90°	13.85	14.03	14.21	14.38	14.55	121°	14.63	15.11	15.60	16.09	16.59
91°	13.87	14.06	14.24	14.42	14.60	122°	14.65	15.15	15.66	16.17	16.69
92°	13.90	14.09	14.28	14.46	14.65	123°	14.68	15.20	15.72	16.25	16.78
93°	13.92	14.12	14.32	14.51	14.70	124°	14.70	15.24	15.78	16.33	16.88
94°	13.95	14.15	14.36	14.56	14.75	125°	14.73	15.29	15.85	16.41	16.98
95°	13.97	14.18	14.39	14.60	14.80	126°	14.75	15.33	15.91	16.49	17.08
96°	14.00	14.21	14.42	14.63	14.84	127°	14.78	15.38	15.98	16.58	17.18
97°	14.02	14.24	14.45	14.67	14.89	128°	14.80	15.42	16.04	16.66	17.29
98°	14.05	14.27	14.49	14.71	14.94	129°	14.83	15.47	16.11	16.75	17.40
99°	14.07	14.30	14.53	14.76	15.00	130°	14.86	15.52	16.18	16.84	17.51
100°	14.10	14.34	14.58	14.82	15.06	131°	14.88	15.56	16.25	16.94	17.62

of 18,500 cubic feet of air at 105°F., find in the table that 1 pound of air (at atmospheric pressure, or 14.7 pounds per square inch, absolute) has a volume of 14.22 cubic feet; then the weight of the air is 18500 ÷ 14.22 = 1301, say 1300 pounds.

In Art. **131**, it was stated that 55 cubic feet of air could be heated 1°F. by 1 B.t.u.; and this is quite accurate enough for

ordinary heating work. But when very accurate results are required, or in those cases where the removal of vapor and widely fluctuating differences in temperature are encountered, as in machine-room heating and ventilation, the quantities of air must be expressed in pounds instead of in cubic feet. Therefore, after determining the number of cubic feet per minute or per hour, change this into pounds per hour by the use of Table II, and then calculate the steam required to heat this air by the methods previously explained.

EXAMPLE.—How many pounds of steam per hour is required to heat dry air from 95°F. to 120°F. when a fan delivers the air at the rate of 21,000 cubic feet per minute?

SOLUTION.—From Table II, the volume of 1 pound of dry air at 95°F. is 13.97 cubic feet; then, the weight of the air heated per hour is $\frac{21000 \times 60}{13.97}$ = 90,200 pounds, very nearly. Since the specific heat of air is 0.241, the number of heat units required to raise the temperature 120° − 95° = 25° is 0.241 × 90,200 × 25 = 543,500 B.t.u. per hour. It was stated in Art. **132** that the heat given up by 1 pound of steam in condensing might be taken as 1000 B.t.u.; hence, the steam required is 543,500 ÷ 1000 = 543.5 lb. per hour. Ans.

139. Relative Humidity.—Moisture may be carried in the air as free moisture, similar to drops of rain in the atmosphere; or, it may be carried as vapor, the air being more or less saturated, varying from dry air containing no moisture to completely saturated air. A cubic foot of air can carry varying amounts of moisture; but when the air is carrying the greatest amount of moisture possible without beginning to deposit it or to turn it into free moisture, the air is said to be **saturated.**

The amount (weight) of moisture actually present in a given volume of air, say in 1 cubic foot of air, is called the **absolute humidity.** The ratio of the amount of moisture in the air at any temperature to the amount at that temperature that would saturate it is called the **relative humidity,** which is usually expressed as a per cent. For instance, at 75°F., a cubic foot of air will be saturated when it contains 9.4 grains of moisture; if it contained only 7.5 grains of moisture at this temperature, the relative humidity would be 7.5 ÷ 9.4 = .80 = 80%. But if it were fully saturated and contained 9.4 grains of moisture at 75°, the relative humidity would be 9.4 ÷ 9.4 = 1 = 100%.

To determine the relative humidity, two thermometers are used. These are placed side by side, but separated a few inches

from each other. One of the thermometers, called the **dry-bulb thermometer,** is like any ordinary thermometer; but the other, called the **wet-bulb thermometer,** has its bulb covered with a cloth or a wick, which is kept saturated with water. On account of the evaporation of the water, which cools the bulb, the wet-bulb reading is always lower than the dry-bulb reading, except when the air is saturated, in which case, the two readings will be the same, there being no evaporation then.

Having taken the two readings, find their difference; then, referring to the chart, Fig. 42, note the curve marked "$T - T_1$ Degrees Fahrenheit," which curves upward from near the lower right-hand corner. Here T is the dry-bulb reading, say 82°, and T_1 is the wet-bulb reading, say 71°; the difference is $82° - 71° = 11°$. The ends of the diagram give the relative humidities in per cent, increasing from the bottom upward; while the top and bottom lines give the dry-bulb (ordinary temperature) readings, which increase from left to right. Very near the $T - T_1$ curve is a series of numbers that fall on curves, which curve downwards to the left; find the one marked 10, and the next one below it is 11, which is the curve corresponding to the difference just found. Follow this curve until it intersects the vertical line through division 82 on the bottom (or top), the dry-bulb reading; through this point of intersection, follow the horizontal that passes through it to the left (or right, whichever is nearest), and note that it corresponds to 58 on the scale of humidity. Consequently, the relative humidity is 58%.

140. Absolute Humidity.—To find the absolute humidity, i.e., the number of grains of moisture per cubic foot in the air, first obtain the relative humidity as above described. Referring again to the diagram, Fig. 42, note a series of curves that curve upwards, like the $T - T_1$ curve, and which are numbered 3, 4, 5, etc. from left to right, near the top of the diagram; these numbers represent the number of grains of moisture per cubic foot that will saturate the air at particular temperatures. To find the number of grains that will saturate the air at 82°, find division 82 on the top line, and note that it comes between curve 10 and curve 12; the space between these two curves therefore represents $12 - 10 = 2$ grains. Curve 10 crosses the upper line (the saturation line) at 77.5, and curve 12 crosses it at 83. These divisions have nothing to do with the number of grains of moisture, but they may be used to proportion the space between

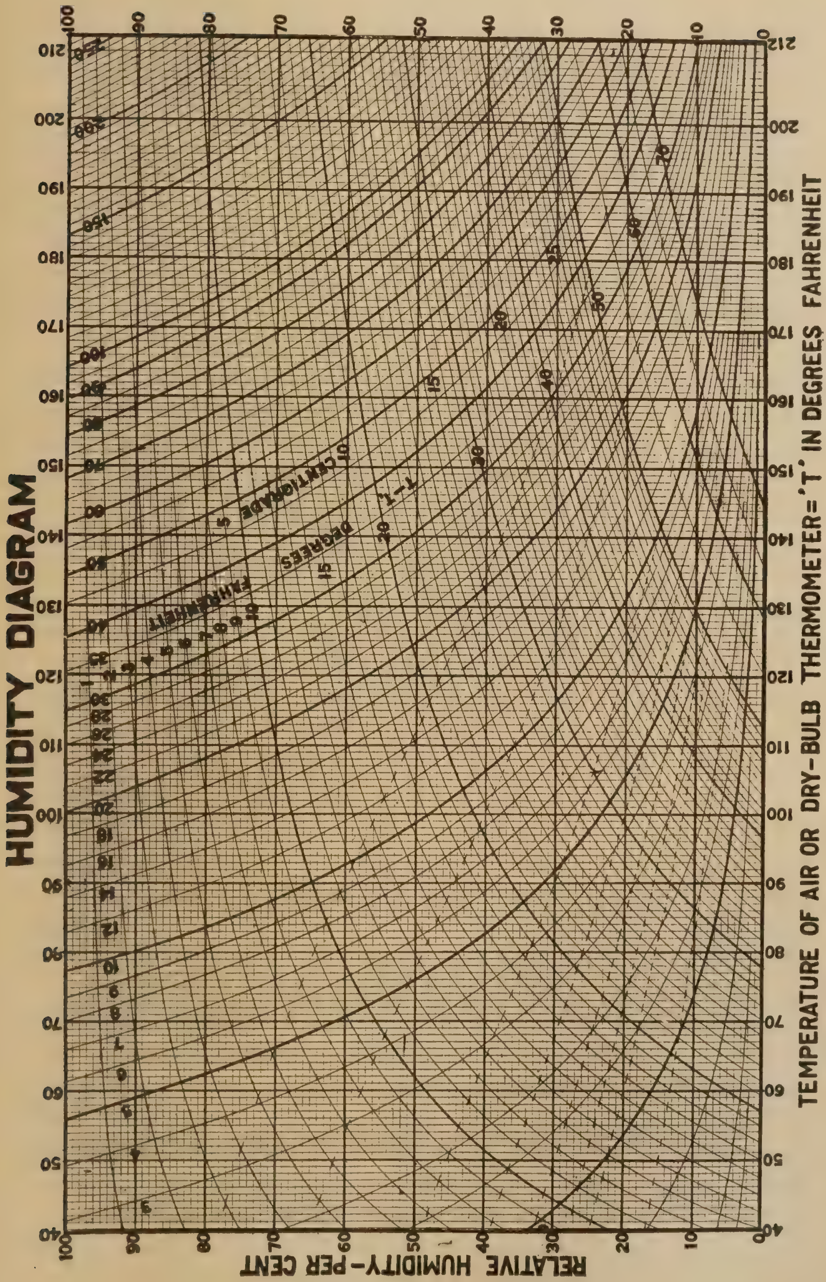
HUMIDITY DIAGRAM
TEMPERATURE OF AIR OR DRY-BULB THERMOMETER='T' IN DEGREES FAHRENHEIT
RELATIVE HUMIDITY—PER CENT
DEGREES CENTIGRADE
DEGREES FAHRENHEIT
T-T1

FIG. 42.

the curves. Thus, the distance between the two curves, measured on the top line, is $83 - 77.5 = 5.5$ divisions; the distance between curve 10 and division 82 (the dry-bulb temperature) is $82 - 77.5 = 4.5$; now since 5.5 divisions represent 2 grains, 4.5 divisions represent $\frac{4.5}{5.5} \times 2 = 1.63$, say $1\frac{5}{8}$ grains. Therefore, the number of grains of moisture that will saturate 1 cubic foot of air at 82°F. is $10 + 1\frac{5}{8} = 11\frac{5}{8}$ grains. In Art. **139,** it was found that the relative humidity under the conditions stated was 58%; hence, the absolute humidity was $11.625 \times 0.58 = 6\frac{3}{4}$ grains per cubic foot.

141. The Dew Point.—If the air be saturated with moisture at any particular temperature, any lowering of the temperature, no matter how slight, will cause the air to deposit a certain amount of moisture on any colder surface it touches, like dew on the grass; hence, the temperature at which the dew begins to form, the saturation temperature, is called the **dew point.** In Arts. **139** and **140,** the relative humidity at 82° was 58%, and the amount of moisture in the air was $6\frac{3}{4}$ grains per cubic foot. If the temperature of air be gradually decreased, a temperature will be reached at which the $6\frac{3}{4}$ grains per cubic foot will saturate it, and any further lowering of the temperature will cause the formation of dew. This point is called the dew point for a dry bulb reading of 82° and 58% relative humidity. To determine this dew point, refer again to the diagram, Fig. 42. Find the point of intersection of the vertical line through division 82 (the dry-bulb temperature) and the horizontal line through division 58 (the relative humidity). Follow the curve that passes upwards through this point (or very near it, in this case), and note that it crosses the upper line at division 66; then the dew point for a temperature of 82° and a relative humidity of 58% is 66°. It is really a small fraction greater than 66°, because the curve passes a very short distance to the left of the point of intersection; but for all practical purposes, it may be considered to be 66°.

The absolute humidity was found to be $6\frac{3}{4} = 6.75$ grains per cubic foot; hence, the dew point might have been found direct from the top line of the diagram, as follows: The 6 curve crosses the top line at division 61.5; the 7 curve crosses at 66; the difference, $66 - 61.5 = 4.5$ divisions, represents $7 - 6 = 1$ grain; $6.75 - 6 = 0.75$ grain; therefore, $.75:1 = x:4.5$, or $x = 3.375$ divisions, and $61.5 + 3.375 = 64.875$, say 65 divisions, and the dew point

is 65°. The slight difference in the two results is immaterial in practical work.

142. Influence of Temperature on Relative Humidity.—The amount of moisture that air can carry at 100% relative humidity varies with the temperature; the higher the temperature the greater is the moisture-carrying capacity of the air. This increase in carrying capacity is very rapid as the temperature of the air increases, as a glance at the diagram, Fig. 42, will show. Referring to the diagram, it will be seen that at 60°, a cubic foot of air can carry only about $5\frac{3}{4} = 5.75$ grains of moisture; but at 90°, it can carry about 15 grains of moisture, and at 100°, it can carry 20 grains of moisture. This is a very important fact to bear in mind in all calculations pertaining to systems for lowering or increasing humidity. At 70°, a cubic foot of air will carry 8 grains of moisture; consequently, if totally saturated air at 60° be heated to 70°, the relative humidity will then be $5.75 \div 8 = 0.72 = 72\%$. If this same air be heated to 100°, the relative humidity will be $5.75 \div 20 = 0.2875$, say $0.29 = 29\%$. In other words, by heating the air fom 60° to 100°, the relative humidity was lowered from 100% to 29%. This is why the belief is so general that heating the air drives out the moisture. On the contrary, the air has the same amount of moisture it had at first, or 5.75 grains per cubic foot; and all that was accomplished by increasing the temperature was to increase the moisture-carrying capacity of the air. If this heated air were to be cooled back to the original temperature of 60°, the relative humidity would again be 100%, as before.

Exactly opposite results are obtained when air is cooled. For instance, air at 100° contains 20 grains of moisture per cubic foot when saturated; at 70°, it can hold only 8 grains; consequently, if saturated air at 100° be cooled to 70°, $20 - 8 = 12$ grains of vapor will condense into water, the air will still be saturated, and the water will appear either as free moisture entrained in the air, or it will be deposited like dew on any cool surface that it touches; this is what causes condensation on the roof of the machine room. This condensation is not due to any increase in the amount of vapor in the air; the air carrying the vapor from the machine at the dew point temperature strikes the cold surface of the roof, where the temperature is lowered below the dew point, and the vapor is condensed on the roof and drips down into the room. Stringing steam coils along the roof of the room serves to heat the

air and keep its temperature above the dew point, thus preventing condensation; the coils do not lessen the amount of vapor in the air.

143. Removing Excess Moisture.—As previously mentioned, when saturated air is cooled, it loses a certain amount of moisture; this principle is utilized in systems for de-humidifying or drying out the air. The air is cooled down below the dew point, usually by passing the air through sprays of water, so that when it leaves the cooling apparatus, the air is at a low temperature, with a consequent low carrying capacity for moisture; it is also drier, since it gave up a certain proportion of its moisture when its temperature fell below the dew point. If this air be heated back to its original temperature, its relative humidity is very low, and it is then in a state that will permit it to absorb more water (moisture). This action is exceedingly important in connection with air-conditioning systems for producing a lower relative humidity than the air would naturally have; and it is the only practical method for removing moisture from the air. In some small installations, attempts have been made to dry out the moisture by chemical means, as by passing the air over calcium chloride or a similar chemical, which absorbs the moisture very rapidly, thus drying out the air. This method has not proved very satisfactory in commercial installations, especially in those of any considerable size, and it is best to depend on the cooling method for drying air.

A very important point to be noted in this connection is the enormous amount of heat that is released when the moisture is condensed in cooling the air. The vapor in the air is very much like steam, and when 1 pound (7000 grains) of steam is condensed, it gives up approximately 1000 B.t.u. If saturated air at 100° be cooled to 70° at the rate of, say, 21,000 cubic feet per minute, it will give up approximately $\frac{21000 \times (20 - 8) \times 1000}{7000}$ = 36,000 B.t.u. per minute, and this must be absorbed in the cooler. This effect is the basis of all the efforts that have been made to extract heat from the vapor that comes from the paper machine; the heat is obtained by cooling the vapor laden air to such a point that a large proportion of the vapor contained in it is condensed into water, an enormous amount of heat being thereby released. This subject will receive further treatment in connection with the discussion of machine-room heating and ventilation.

144. Fans.—At this point, a few words regarding fans will be appropriate. There are many types on the market, and the selection of the proper fan for some particular use may well be left to the manufacturer or to the plant engineer. However, some information concerning them will be of advantage to the ordinary employe.

Fans have peculiar characteristics under different load conditions; consequently, considerable detailed experience is required in order to select the most efficient fan. Ordinary fans for moving air may be divided into two general classes; the so-called disk fan, and the so-called centrifugal fan.

145. Disk Fans.—The disk fan has many sub-classes, such as the propeller fans, the multi-blade disk fans, the screw propeller type, etc. In general, however, they all move the air parallel to the shaft by means of blades that slice off the air and drive it crosswise through the casing; or, if there is no casing, as in the ordinary house ventilating fan, the air is forced from one side of the fan to the other, passing between the blades parallel to the shaft. If the blades are set at a very acute angle to the axis of the shaft, a less volume of air will be handled (if the plane of the blades were at right angles to the axis of the shaft, no air would be moved), but a greater pressure can be maintained than would be the case if the blades made a greater angle with the shaft.

The most serious defect in the design of a propeller fan is that the speed of the wheel (blades or propeller) increases as the distance from the axis increases. The axis of the wheel is not moving at all, while the rim is traveling at a high speed. If the blades are flat, that is, if they make the same angle with the shaft throughout their entire length, the air will be delivered at a much higher pressure from the rim than from a point near the center. It is to offset this defect that many of these fans have twisted blades or cupped blades, so that the variation in the angle made at different points on the blade with the shaft will tend to make up for the higher speed at the rim. However, even under the best conditions, if any considerable resistance be put on a fan of this type, it will allow air to pass backwards through the center of the wheel, which greatly decreases the capacity of the fan to deliver air. Therefore, a disk or propeller type of fan should be used only when the air is moved with little or no resistance. This type is satisfactory for blowing air from one room to another, or to set in the wall of a machine room to discharge exhaust air

outdoors. In the latter case, however, trouble is sometimes caused by heavy winds blowing against the fan, and shields or swinging ventilators should be placed on the outlet of the fan, to protect it from adverse winds. Disk or propeller fans should not be used with any considerable system of ducts. (A **duct** is a tube or pipe for conducting a fluid, as air or water.)

146. Centrifugal Fans.—The centrifugal fan is similar in principle to the centrifugal pump. When the blades are flat, their planes are parallel to the axis of the shaft. The blades are enclosed in a casing or housing, and they extend (radiate) outwards from the center. The air enters at the center (the inlet), and is forced along the blades to the shell and through the outlet by the action of centrifugal force. The pressure of the air through the outlet depends on the speed of rotation of the blades;—the greater the speed the greater the pressure;—hence, much greater pressures can be obtained with this type than with a disk or propeller fan. The fan may be of the standard paddle-wheel type, with from 6 to 12 blades; or it may have a multiplicity of small blades and also have the blades cupped forward. This latter type of fan will deliver more air for the same size than the paddle-wheel type; but, this very increase in capacity makes it necessary to use more discretion in selecting the fan. The efficiency of these fans varies from 40% to 70%, at different points on the load curve; from which it may be seen that a fan may be selected to do the work that will take nearly twice as much power as another fan of proper size. A fan and a blower are illustrated in the Section on *Sulphate Pulp*, Vol. III.

HEATING AND VENTILATION OF VARIOUS DEPARTMENTS

THE GRINDER ROOM

147. Statement of the Problem.—The heating and ventilation of the grinder room is a very important problem. The grinders discharge a considerable quantity of vapor and also give off a considerable amount of heat. In winter it is necessary not only to introduce heat but also to carry away the vapor that would otherwise condense in the building, which would make the room very uncomfortable and would cause deterioration in the building

structure. In summer the problem is not one of heating, but of cooling the room, and of introducing sufficient air to ventilate it properly and to remove the moisture rising from the grinders. When pocket grinders are used, wood is often stacked up in the room, which materially interferes with the proper circulation of the air.

148. Fan and Heater System.—The proper system for a pocket-grinder room consists of a fan and heater, which discharges air into the building through a series of distributing ducts. In the winter, warm air is supplied by drawing it over the steam coils, which are so arranged that they may be shut off in the summer, when unheated air is supplied instead. In the winter, it is well to arrange that some of the heated air shall be discharged toward the floor, in order to offset the effects of the cold wet floor on which the men work; the greater part of the heated air should be discharged along the roof, to keep the vapor above the dew point and thus prevent it from condensing on the roof. In the summer, but very little air need be discharged along the roof, since all the ventilators and skylights are usually open, thus allowing the air and vapor to pass out; also, the roof is warm, which prevents condensation. Practically all the air should be discharged near the floor, so that when it rises, it will carry with it the hot air and vapor, which usually cling near the floor of the grinder room.

The volume of air necessary for a grinder room is very much larger than that required simply to carry away the heat it contains. Thus, whereas in an ordinary building, it will suffice to put in a quantity of air equal to the volume of the room every 20 minutes, at a temperature of, say, 140°, it is often necessary to put in many times this volume in the grinder room, but at a much lower temperature, say 90°, the total number of heat units being carried into the room being the same in either case. Re-circulation is not advisable in the grinder room, because it is necessary to supply fresh air, which has great capacity for absorbing moisture when heated, in order to remove the fog and vapor from the grinders.

149. Exhaust Systems.—A system is now being introduced in which the vapor is drawn away from the pocket grinders without allowing it to spread through the room. This is accomplished by connecting suction air ducts to the suction boxes in the

individual pocket grinders; as rapidly as the vapor is formed, it is drawn to the exhaust fan and discharged to the atmosphere. This system obviates the necessity for having a large volume of air to keep the roof dry and to carry away the vapor in the room. Further, when this system is used, the problem of heating the grinder room is reduced to an ordinary straight heating proposition, and the air can be re-circulated, as in any other type of building. Also, it naturally follows that there is greater economy in the use of steam, since the steam required to heat the grinder room is then but a small proportion of that required to heat the very large volume that is necessary for ventilation under the usual grinder-room conditions.

150. Rooms with Magazine Grinders.—The problem is altered very materially when magazine grinders are used, and these are now being employed quite generally. The wood is fed into the grinders from the floor above. If allowed to take its natural course, the vapor from a grinder will leak into the grinder room; it will also pass up through the stack and through and around the wood, with the result that unless the trap doors leading to the charging room above are kept tightly closed, the vapor will enter the wood room. The charging room is full of cold, wet wood, and the moisture (vapor) entering this room will be quickly cooled to the dew point, thereby causing it to condense and to be deposited on the walls, windows, and roofs. It is therefore best to connect the grinders to an exhaust system, which will draw the vapor direct from the stacks. This keeps the vapor from entering the charging room above; it also tends to draw it upwards and away from the grinders, thus preventing the vapor from entering the grinder room. It will be understood, of course, that the air and vapor that is drawn away by the exhaust system must be replaced with an equal volume of fresh air, but this volume is very much less than that required in an ordinary pocket-grinder room. The charging room above must also be heated and ventilated; and sufficient fresh air must be put in to take care of and absorb the vapor that naturally rises from the large surface of wet wood, as well as that which may come from the grinders below.

The use of magazine grinders creates another problem—to remove the large amount of heat that is generated by the motors that drive the grinders. If possible, these motors should be placed in a separate room, away from the moisture in the grinder room. Usually, it is not necessary to heat this room, the problem

being to remove the excess hot air; even in winter, air should be removed from these motors. In many cases, cold fresh air is supplied through the motor windings, to keep the motors cool, the air passing through the motors and entering the room at a relatively high temperature. In winter this is both warm and very dry, and it is well to utilize it in heating the grinder room; in summer, of course, it must be thrown away. The air may be supplied to the motors by a fan; but, more often, it is admitted under the motors, and the fan action of rotors sucks the air through the motors. This air may be cooled artificially by passing it through sprays of water, if very heavy overloads are carried on the motors; this tends to keep the windings cool and to prevent overheating. In any event, this air should be very clean,—free from dirt, grit, and other foreign particles,—and it is well to put in air filters, to make certain that dust, dirt, etc. do not enter the motor windings.

THE MACHINE ROOM

151. A Ventilation Problem.—The machine room constitutes the most important problem concerning the heating and ventilation of the paper mill. The problem is much more one of ventilation than of heating. When the paper machine is running, the heat given off by the dryers is usually sufficient to maintain the machine room at the proper temperature, with the possible exception of the ends of the room; hence, the heating of the machine room is a minor consideration. The question of ventilation, however, is extremely important, because the large amount of vapor given off by the dryers must be removed from the building without allowing it to condense on the walls. As previously stated, if air mixed with vapor be cooled, the moisture-carrying capacity of the air is decreased greatly; and if it be cooled below the dew point, moisture will be deposited on any surface cooler than the air. Though the air surrounding the machine may be only 70% saturated, when it passes down to the wet end of the machine, it will cool below the dew point, and the roof and windows will condense the vapor contained in it, even though no extra moisture was produced at the wet end.

152. Amount of Vapor to be Handled.—The amount of vapor given up by the paper varies with the kind of paper being made

and with the type of machine that is making it. Roughly, however, 2 pounds of water is evaporated by the dryers for every pound of paper produced. The exact amount, which varies with the per cent of water in the paper on entering and leaving the dryers, may be determined as follows:

Let M_1 = the per cent of moisture in paper entering the dryers;
M_0 = the per cent of moisture in the dried (finished) paper;

$$m_1 = \frac{M_1}{100},$$

$$m_0 = \frac{M_0}{100}.$$

Then, 1 pound of finished paper contains m_0 pounds of water and $1 - m_0$ pounds of bone-dry fiber. The weight of this paper on entering the dryers is $\frac{1 - m_0}{1 - m_1}$ pounds, and the weight of water evaporated is $\frac{1 - m_0}{1 - m_1} - 1 = \frac{1 - m_0 - 1 + m_1}{1 - m_1} = \frac{m_1 - m_0}{1 - m_1}$ pounds, which is the weight of water evaporated per pound of finished paper, since only 1 pound was considered here. Representing this weight by w,

$$w = \frac{m_1 - m_0}{1 - m_1} = \frac{\frac{M_1}{100} - \frac{M_0}{100}}{1 - \frac{M_1}{100}} = \frac{M_1 - M_0}{100 - M_1}$$

For example, if the paper entering the dryers contains 66% water, and the dried (finished) paper contains 7% water, the weight of the water evaporated per pound of finished paper is

$$w = \frac{66 - 7}{100 - 66} = 1.735 \text{ pounds.}$$

If preferred, the following table may be used instead of the formula:

TABLE III

Water in wet paper (per cent)	Water evaporated per pound of dried paper					
	Water in dried paper (per cent)					
	5	6	7	8	9	10
60	1.375	1.350	1.325	1.300	1.275	1.250
61	1.436	1.410	1.385	1.359	1.333	1.308
62	1.500	1.474	1.447	1.421	1.395	1.368
63	1.568	1.541	1.514	1.486	1.459	1.432
64	1.639	1.611	1.583	1.556	1.528	1.500
65	1.714	1.686	1.658	1.629	1.600	1.571
66	1.794	1.765	1.735	1.706	1.676	1.647
67	1.879	1.848	1.818	1.788	1.758	1.727
68	1.969	1.938	1.906	1.875	1.844	1.813
69	2.065	2.032	2.000	1.968	1.935	1.903
70	2.167	2.133	2.100	2.067	2.033	2.000
71	2.276	2.241	2.207	2.172	2.138	2.103
72	2.393	2.357	2.321	2.286	2.250	2.214
73	2.519	2.481	2.444	2.407	2.370	2.333
74	2.654	2.615	2.577	2.538	2.500	2.462
75	2.800	2.760	2.720	2.680	2.640	2.600

The factors given in Table III are for unit weight of paper delivered by the dryers; that is, if the weight of the paper delivered be expressed in pounds (or tons) this weight multiplied by the proper factor will be the number of pounds (or tons) of water evaporated by the dryers. For example, suppose the paper entering the dryers to contain 38% bone-dry fiber, and that it contains 8% moisture when it leaves the dryers; then, if the mill turns out 25 tons of paper per day, how much water is evaporated by the dryers? The per cent of moisture in the paper entering the dryers is $100 - 38 = 62$. Referring to the table, find 62 in the first (left-hand) column; in the same row, in the column headed 8, find 1.421; then, the weight of water evaporated in making 25 tons of finished paper is $1.421 \times 25 = 35.53$ tons.

153. The Air Supply.—Sufficient air must be passed through the machine room to absorb this enormous amount of vapor and

carry it outside. Evidently, the greater the amount of moisture that can be carried per cubic foot of air the less will be the amount of air required to be passed through the machine room. In Art. **134,** it was shown that introducing even 20,000 cubic feet of air per minute in zero weather necessitated the use of a large amount of steam (1527 pounds per hour); therefore, it will be readily seen that the amount of steam required to heat the air for the machine room is a very large item. It is necessary to use outside air, because the air that carries the vapor must be discharged to the atmosphere and an equal volume must be introduced to the machine room in some way. It will be useless to take this air from other parts of the building, since this only transfers the heating load from the machine room to other departments; the air must finally come from outside, and it might as well come direct to the machine room.

It will be apparent at once that *hooding* the machine tends to confine the vapor more closely and enables it to be carried from the machine at a higher temperature, which means that the air has a greater carrying capacity for moisture. Furthermore, the air will usually carry more moisture per cubic foot, because the vapor is not allowed to spread through the room and become diluted. Regardless, however, of how much moisture may be carried from the ordinary paper machine per cubic foot of air, a certain volume of air must pass through the room, if the paper is to be dried; this volume is so large as to outweigh all the necessities for heating only, and the movement of air in the machine room thus becomes a purely ventilating problem. Cold (unheated) air might be introduced into the room; but if this be done, it tends to keep the roof and the ends of the building cold, and the air in the machine room will cool sufficiently to cause it to condense. Even if there were no condensation, no economy in the use of steam would result; it would then be necessary for the dryers themselves to evolve sufficient heat to make up the deficiency, the air would pass out of the ventilators at a lower temperature, and this would mean more air and, consequently, still more heat. The system that is most economical in the use of steam is the one that will carry the air away with the highest amount of moisture, which means, of course, at a sufficiently high temperature.

154. The Steam Supply.—By taking the wet-bulb and dry-bulb temperatures of the moisture-laden air passing out of the ventilators, the number of grains of moisture carried in each

cubic foot of air can be readily determined by means of the humidity diagram, Fig. 42. From this should be subtracted the number of grains of moisture per cubic foot in the outside air, which can be found similarly. The difference thus found will be the number of grains of moisture per cubic foot that is absorbed from the machine; and from this can be found the number of cubic feet of air per minute that must pass out of the room to remove the vapor. To find this last, estimate carefully the weight of the water evaporated by the dryers in grains per minute, and divide this by the number of grains of moisture per cubic foot that is removed by the air; the quotient so obtained should be increased somewhat to allow for the moisture coming from the wet end of the machine. Then, by means of Table II, find the specific volume of the air for the temperature and humidity of the air being discharged, divide this into the number of cubic feet discharged per minute, and the quotient will be the number of pounds of air discharged per minute to remove the vapor, which may be represented by w. Let t_i = the temperature of the air (inside air) discharged; t_o = the temperature of the outside air; and U = number of British thermal units per minute required to heat the air; then,

$$U = 0.241w(t_i - t_o).$$

The procedure is best illustrated and explained by an example.

EXAMPLE.—(*a*) The dry-bulb temperature of the outgoing air is 100°, and the wet-bulb temperature is 98°; the dry-bulb temperature of the outside air is 50°, and the wet-bulb temperature is 43°; the number of tons of water evaporated per day of 24 hours is 35.53 tons (see Art. **152**); how many pounds of steam per hour is required to heat the air? (*b*) If the temperature of the outside air is 0°, how many pounds of steam per hour is required to heat the air?

SOLUTION.—The difference of the wet- and dry-bulb readings for the inside air is 100° − 98° = 2°; hence, referring to Fig. 42, the relative humidity at 100° is 92.7%, and the number of grains of moisture in 1 cubic foot of the air is 20 × 0.927 = 18.54 grains.

The difference between the wet- and dry-bulb readings for the outside air is 50° − 43° = 7°; hence, referring to Fig. 42, the relative humidity at 50° is 56%. Since the number of grains of moisture required to saturate the air at 50° is 4.1 grains; the number of grains of moisture in the air when the relative humidity is 56% is 4.1 × 0.56 = 2.3 grains. Subtracting the second result from the first, 18.54 − 2.3 = 16.24 grains of moisture absorbed and taken out per cubic foot of the air.

Referring to Table II, the specific volume at 100° and 75% humidity is 14.82 cu. ft.; at 100° and 100% humidity, it is 15.06 cu. ft. To interpolate for 100° and 92.7% humidity, form the proportion

$$(15.06 - 14.82) : (x - 14.82) = (100 - 75) : (92.7 - 75);$$

or,

$$0.24 : (x - 14.82) = 25 : 17.7;$$

from this latter proportion, $x = 14.99$, say 15 cu. ft. per pound.

The number of pounds of water evaporated per minute is

$$\frac{35.53 \times 2000}{24 \times 60} = 49.35 \text{ lb. of water per min.}$$

The number of cubic feet of air per minute required to remove this water is, since there are 7000 grains in 1 pound,

$$\frac{49.35 \times 7000}{16.24} = 21{,}271 \text{ cu. ft. per min.}$$

To allow for the wet end of the machine, assume that it is necessary to heat 22,000 cu. ft. of air per min.; then, the weight of this air is

$$\frac{22000}{15} = 1467, \text{ say } 1470 \text{ lb.}$$

The number of British thermal units required to heat the air is

$$U = .241 \times 1470(100 - 50) = 17{,}714 \text{ B.t.u. per min.}$$

Taking the old figure of 1000 B.t.u. given up by 1 pound of steam in condensing to water, the number of pounds of steam per hour required to heat the air is

$$\frac{17714 \times 60}{1000} = 1063 \text{ lb. of steam per hour.} \quad \text{Ans.}$$

(*b*) An examination of the humidity diagram, Fig. 42, shows that it does not give the grains of moisture per cubic foot for temperatures lower than 40°; however, it is clearly seen that, even at saturation, the weight of moisture per cubic foot in air at 0° will be exceedingly small, and that if this be multiplied by the relative humidity, the product will be still smaller. In the solution to (*a*), it was found that at 100° and 92.7% humidity, the air could carry away 18.54 grains of moisture per cubic foot; at 0° outside, it may be assumed that the air can carry 18 grains of moisture when the temperature inside is 100° and the humidity 92.7%. Therefore, the number of cubic feet of air required per minute is

$$\frac{49.35 \times 7000}{18} = 19{,}192 \text{ cu. ft.}$$

To allow for the wet end of the machine, this may be taken as 20,000 cu. ft. $= \frac{20000}{15} = 1333$ lb. of air per min.

The number of pounds of steam required per hour to heat this air is

$$\frac{0.241 \times 1333(100 - 0) \times 60}{1000} = 1867.5 \text{ lb.} \quad \text{Ans.}$$

It will be observed that less air is required in the second case, but more steam is needed to heat the air; because the temperature is raised only 50° in the first case, while it is raised 100° in the second case.

The foregoing method of calculating the amount of steam required is not quite accurate, because some of the heat utilized in heating the air was derived from the dryers. This is offset, however, by the radiation loss in heating the machine room, and in practice it has been found that one virtually offsets the other. Consequently, this method of calculating the amount of steam required to heat the air for ventilating the machine room may be considered as being sufficiently accurate for all practical purposes.

155. Two Important Features.—Two features of the problem will at once impress the reader as being of primary importance. The first is the total amount of water evaporated by the dryers. It can be readily perceived that if any change can be made at the wet end of the machine which will reduce the amount of water to be evaporated by the dryers, this will reduce the amount of steam required to heat the air; under certain conditions, this loss may be reduced considerably.

The second important feature is that the greater the amount of moisture carried out per cubic foot of air the smaller will be the amount of air required; under certain conditions, this will also reduce the amount of steam necessary to heat the air. It is not advisable, however, to carry the air above a certain saturation point, i.e., the relative humidity must not exceed a certain amount; because, otherwise, the room will be humid, hot, and very uncomfortable. A moist, uncomfortable room may be quite efficient in the use of steam, while a comparatively dry, cool room may be very inefficient; the proper dividing line can be determined only as the result of considerable practical experience.

156. Effect of Radiation Loss.—Up to this point, no account has been taken of the radiation loss. There is a general impression that a building that will resist heat radiation will require less air to pass through the machine room; but this idea is fallacious, provided the loss by leakage is confined to reasonable limits. As has already been made evident, the amount of air passing through the room is contingent only on, first, the amount of moisture evaporated from the dryers, and, second, the amount of moisture per cubic foot of air passing through the ventilators.

157. Temperature of the Air.—The temperature at which the heated air should enter the room depends on the building construction. The air should pass through the ventilators at some

fixed temperature, which should be, of course, as high as possible, consistent with comfort and efficiency. However, before the temperature of the air has reached this point, the air must have provided sufficient heat to offset the radiation loss; therefore, it must be supplied at a temperature high enough to overcome the radiation loss and still go up the stacks at the proper temperature.

158. Importance of Well-Insulated Roof.—A very cold roof will cause vapor-laden air to condense, even though the relative humidity of the air be satisfactory; this is why it is so important to have a properly insulated roof. Further, the air being introduced to the machine room must be supplied along the roof in sufficient quantity to take care of the radiation loss, and it will be at once apparent that more air is required along a cold roof than along a well-insulated roof. Consequently, the less the amount of air required on the roof the greater will be the amount available for use below.

159. Effects Produced by Windows.—Windows that have a very high rate of radiation transmission will condense moisture out of the air when it will not condense on other parts of the building. While it is possible to heat and circulate enough air to prevent the windows from condensing the vapor contained in it, this will require more air, and a consequent greater steam consumption than is necessary to keep the rest of the building in proper condition. Therefore, it may be advisable to put in double windows; otherwise, the windows may be allowed to condense the vapor, the condensation being carried away in gutters provided for this purpose.

160. Recovery of Heat.—The air leaving the machine room carries with it in the form of vapor all the water taken from the paper by the dryers. The fact that an enormous amount of steam is required to heat this air has led to efforts to recover the heat contained in the vapor. A large proportion of the steam entering the dryers is used to supply the heat necessary to vaporize the water (latent heat of vaporization); roughly, 1 pound of steam is required simply to change 1 pound of water into 1 pound of vapor. If, therefore, by some means, this same pound of vapor can be turned back into water, approximately 1000 B.t.u., or the equivalent of 1 pound of steam, will be recovered. This principle is the basis of all efforts to recover this waste heat; and the amount of heat that it is possible to recover in this way is

enormous—so enormous that it is difficult to devise methods of using it.

If cold water were used to cool the vapor and condense this moisture, the water would be heated; but it would be quite a problem to determine what to do with the heated water. It might be used in the beaters of a board mill or a kraft mill; but it must be remembered that the vapor is not at a very high temperature, and the water, therefore, cannot be heated up very hot. Still, a large quantity of water can be heated, in fact, a larger quantity than can be used in the beaters. Fortunately, or unfortunately, it is necessary to take in a large amount of fresh air, and this at once presents the opportunity for utilizing the recovered heat. The temperature of the vapor rising from the machine is higher than that of the air required for ventilating the room; it is quite practical to heat this air by means of the waste heat from the vapor, which really is steam of low pressure and low temperature, and which has wonderful qualities for heat recovery. A mill that discharged thousands of pounds of exhaust steam to the atmosphere, but used at the same time thousands of pounds of live steam to heat the air, would be very seriously criticized; yet, today, hundreds of mills are doing just that. They are discharging to the atmosphere thousands of pounds of very low-pressure steam, and they are using thousands of pounds of live steam, either in the heating system or in the dryers, to heat large volumes of cold air, which they pass through the machine room and discharge to the atmosphere.

The diagram, Fig. 43, shows to what an enormous extent different methods of conveying the moisture (vapor) to the atmosphere affect the cost of the steam required per ton of finished paper. The costs here given are based on a steam cost of 60 cents per 1000 pounds of steam—a fair average for most mills—and the paper is assumed to enter the dryers with 30% dry fiber and to leave with 7% moisture.

Four different machine conditions are represented. The four upper curves *A*, *B*, *C*, and *D* give the costs per ton of paper for heating the air passing through the machine room under ordinary conditions; the four lower curves, similarly lettered, show the costs after installing an efficient economiser for extracting the heat from the waste vapor. Curve *A* is for an exceptionally efficient cross-ventilation system; curve *B* is for the most efficient closely hooded machine; curve *C* is for the average hooded

machine; and curve D is for the average machine without hoods. Suppose the temperature of the outside air to be 15°F.; then, for the average machine without hoods, the cost per ton is \$2.03, which is found by following up the line passing through 15° (half way between 20° and 10° at the bottom) until it intersects

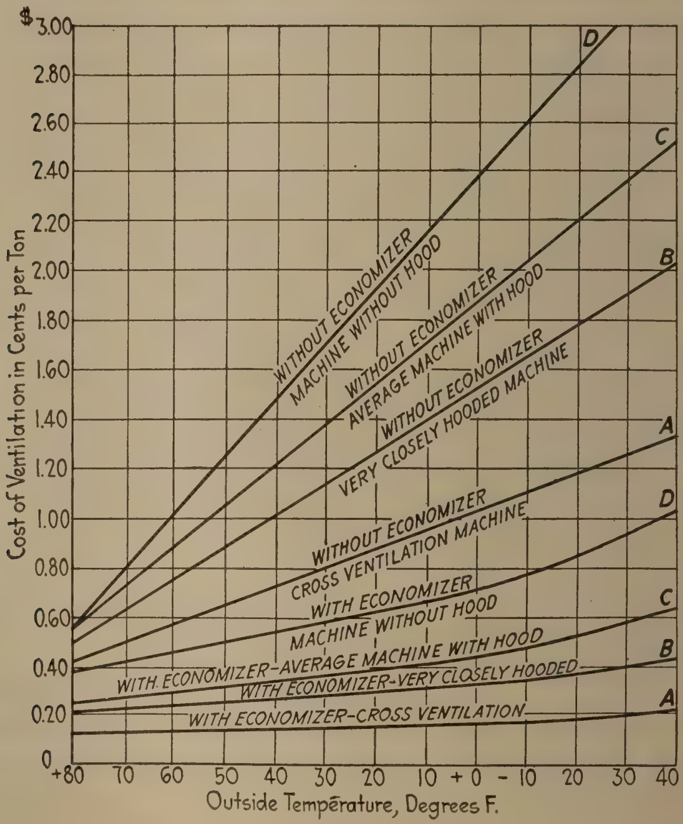

FIG. 43.

the upper curve D, and then following horizontally to the left to 2.03. For the same outside temperature, 15°, the costs for the other conditions are: for C, \$1.63; for B, \$1.32; and for A, \$0.84. After installing an economiser, these costs were reduced respectively to: for D, \$0.64; for C, \$0.40; for B, \$0.28; and for A, \$0.16. The saving between the two extreme conditions is \$2.03 − \$0.16 = \$1.87 per ton. For a production of 25 tons per day, the saving is \$1.87 × 25 = \$46.75 per day.

OTHER DEPARTMENTS

161. The Wet-Machine Room.—In many mills, wet machines are used for forming pulp laps, and forming press board or similar products that do not go through the ordinary paper machine. Since the wet pulp surface gives off a certain amount of vapor and moisture, a certain amount of fresh air should be used in the heating and ventilating system. As these pulp laps and boards are not dried in any special manner in the wet-machine room, the amount of moisture given off is comparatively small; and it will often be found that the ordinary leakage from the building will take care of this, the problem becoming a straight heating one. This depends somewhat on local conditions; but when a wet-machine room is almost entirely surrounded by other rooms, it is well to supply fresh air from outside at all times—especially in the summer.

162. Grinder-Stone Storage Rooms.—It is very essential that a uniform temperature above the freezing point be maintained in any room where grinder stones are stored. It need not be a high temperature, or even a comfortable temperature for an employe, as he enters the room only at infrequent intervals. However, a stone that has been kept for a considerable length of time in a properly heated room, free from excess of humidity, is greatly improved; and it is well worth while to give a little attention to this department.

163. Beater Rooms.—The beater room sustains losses because of radiation through the walls and because of leakage of air; furthermore, a certain amount of moisture arises from the beaters, and this must be considered in connection with any proper heating and ventilating system. Where mills use hot water in the beaters, the problem of ventilating the beater room is much more important than that of heating it; in many cases, it may even approach that of ventilating the machine room. When using cold water in the beaters, a system similar to that in use in the ordinary departments—with provision for either returning a part of the air or for using fresh air—will answer the purpose. If ventilators are installed above the beaters, all the air that passes out of these ventilators must be replaced with fresh air; otherwise, there will be a large leakage of cold fresh air inwards to take its place, which will not only keep the outer parts of the building cold but will also cause fog and condensation.

164. Rag Rooms.—It is very important that the rag room of mills using rags should be properly heated and ventilated. The rags are usually put through the dusters, to remove the excess dust and dirt. Even then, however, the girls that cut and sort the rags encounter a large amount of dust and lint, which is very disagreeable and is positively injurious to their health. The rags should be sorted on tables, so arranged with screen openings and connected to exhaust ducts that the air is drawn downwards through these openings or screens; then, instead of rising in their faces, the dust is drawn downwards and removed from the building. This often entails the use of a large amount of air, which must all be replaced by the heating and ventilating system; this air must be heated sufficiently to heat the room properly. Also, if possible, the entering air should be humidified to some extent, since dust will not float around so much in a moist atmosphere. It is quite important to prevent drafts in the rag room; the very heavy suction on each bench causes a flow of air to the bench, which is liable to cause the girls to take colds. If a sufficient amount of properly warmed air is not supplied to the room, the cold air will leak in around the doors and flow toward the sorters, which is extremely disagreeable.

165. Bleach Boiler House.—In the bleach boiler house, it is seldom necessary to supply additional heat, but a very large volume of air must be removed from it, which necessitates a considerable fan capacity. The only problem that here requires careful consideration is the supplying of the air to replace that exhausted from the boiler house. If the bleach boiler house opens into the other departments of the mill, a tremendous flow of air from the other departments will often result, which will make it impossible properly to heat the other departments. This problem is one of local conditions, and no general rules can be laid down to govern it.

166. Finishing Rooms.—The finishing rooms naturally belong to one of two classes: first, the finishing room that is similar to that in the newsprint mill, which is used almost entirely as a wrapping and shipping department; second, the finishing room of book-paper mills, coating mills, etc., where the paper is calendered or further processed.

In the case of the newsprint finishing room, sufficient fresh air should be admitted to offset any possible leakage of air from the

finishing room into the machine room. The air ducts should be carried in the trusses, and a sufficiently large volume should be introduced into the room to keep the temperature from becoming too high. The temperature of the air may not be so high as to overheat the room insofar as the average temperature is concerned, but it may produce an extremely dry atmosphere; this has a tendency to overdry the edges of the rolls of paper, and it may mean such a small volume of air that a very slight leakage upsets all heating calculations. This leakage is especially important in those mills where the cold train shed is more or less open to the finishing room.

In the second class of finishing room, the ideal system is one that will supply sufficient air and heat, and which will also maintain an approximately constant relative humidity in the room. An overdry finishing room in winter not only causes static electricity on the calenders—a very serious detriment—but also renders it harder to secure proper finish on the paper; and, by overdrying the edges of the stacks of paper, it upsets all the efforts that have been made up to that point to produce a uniformly moist sheet of paper. The air should be introduced in such a manner that no direct flow of air will be directed toward the calender stacks, or trouble will be encountered in running the stacks. Automatic control of the temperature and humidity is an excellent investment in the finishing rooms of the finer grade mills.

167. Container Buildings.—The heating of the (paper) box factory or (paper) container building has usually been considered an unimportant detail, a system of steam coils being strung along the wall or on the ceiling, to keep the temperature sufficiently high to make the employes comfortable. However, a dry, harsh atmosphere in the container building causes the boxboard to become overdry on the surface, with poor results when the board is bent or folded; it also causes static electricity, which greatly interferes with the fast and satisfactory operation of the container machine. Furthermore, benches are usually run along the walls for sorting or cutting, and large stacks of boxboards are piled in various parts of the room; consequently, a system of steam coils along the wall does not properly take care of the heating of the building.

A container building is usually of large dimensions and of considerable height, with many skylights and other glass windows.

It was common practice formerly to string steam coils along the trusses; this kept them out of the way, and the heat could be introduced into the room without seriously affecting the stacks of boards. Since hot air rises, this is not an economical system; in fact, a room heated in this manner may have a temperature 20° to 25° higher at the roof than on the floor level, and the loss of heat through the large roof and skylights is a serious item. A fan system that introduces air through ducts carried in the trusses, and so arranged that the air is uniformly discharged over the room, is much more satisfactory. Further, by combination with a humidifying system, automatic control of the temperature and humidity can be obtained, thus doing away with the harsh, dry atmosphere that is otherwise characteristic of the container building. This means that the employes can work at a lower temperature and still be comfortable, and there is a great increase in the efficiency of all work done on the container machines. In the summer, it is usually advisable to discharge outside air through the system. No attempt need be made to regulate the humidity, unless it be on extremely cool mornings or late in the afternoon, the ordinary outdoors humidity being sufficient in summer.

168. Storage Rooms.—As a general rule, the storage building need be heated only sufficiently to enable employes to work in reasonable comfort. In boxboard mills, the waste-paper storage room is usually located over the beater room; it is necessary to heat this room, or moisture will enter from the beater room below, through the stairs or elevators. Unless the storage room be reasonably warm, the roof will condense the moisture, making it a very disagreeable place and causing injury to the structure.

It is generally advisable to have a good heating system in places where pulp is stored. Mills that bring in pulp to be manufactured into paper, have large quantities of frozen pulp to be placed in the storage house, and this pulp should be thawed before going to the beaters; hence, when estimating a heating system for pulp storage, the frozen pulp must be considered. A heating system that will satisfactorily heat an empty storage building will prove very inadequate when the building is filled with frozen pulp.

Usually, it is not necessary to use fresh air in the pulp storage building; either a fan system of discharging hot air that has been re-circulated from the room or a steam-pipe system that has

pipes strung along the walls, may be used. If the latter system is adopted, particular care should be taken that the pulp is not piled in such a manner as to shut off the steam coils from the rest of the room; otherwise, it will be found that the space between pulp and the outside walls will be very warm, while the remainder of the room and the side of the pulp farthest from the walls will be almost unaffected by the heat.

169. Screen Rooms.—A screen room presents two distinct problems: the first is heating it in the winter; the second is a purely ventilating problem in the summer. The average screen room is a wet, cold, disagreeable place in the winter, and is a hot, humid place in the summer. The arrangement of the screens and knotters make it very difficult to heat and ventilate in many cases.

Many screen rooms are so located that it is not possible to have any outside windows, and this makes the problem very much harder. Further, the pits under the floor give off hot vapor, which may not only rise into the screen room but may also cause a great deal of excess heat in the summer. There is no department in the mill, with the exception of the machine room, that has greater need for proper heating and ventilation than the screen room. It will often suffice to put in large exhaust fans for removing the air in the summer; but it should be remembered that this air must be replaced in the winter, and a definite air supply system should be provided. For summer conditions, the air should be discharged toward the floor, so as to drive the heat and vapor toward the roof, where the ventilating fans should be located. A considerable volume of fresh air is necessary at all times in the screen rooms.

GENERAL MILL EQUIPMENT

(PART 3)

EXAMINATION QUESTIONS

(1) What is meant by radiation loss, and what factors influence it?

(2) Discuss the matter of loss by leakage.

(3) What is the average value of the radiation loss through the stone walls of a building in 11 hours and 40 minutes when the temperature inside is 68° and the temperature outside is 22°, if the building is 75 ft. by 145 ft., and the wall is 38 ft. high and 20 in. thick? Ans. About 3,410,000 B.t.u.

(4) (*a*) In practice, what may be assumed as the number of cubic feet of air that can be raised 1°F. in temperature by 1 B.t.u.? (*b*) Explain how this value is obtained.

(5) (*a*) What may be taken as the average number of heat units radiated per hour from a system of heating coils? (*b*) In practice, how many heat units may be considered as given up by the condensation of 12,500 lb. of steam?

(6) (*a*) Compare heating by direct radiation with heating by the fan system. (*b*) Under what conditions should each be used? (*c*) Which system is the more economical, and why?

(7) Under what conditions should the air for heating and ventilation be measured (*a*) in pounds? (*b*) in cubic feet? (*c*) How many cubic feet will 2325 lb. of dry air occupy at 87°F., under ordinary atmospheric pressure?

Ans. (*c*) About 32,000 cu. ft.

(8) A fan delivers 23,500 cu. ft. of dry air per minute; how many pounds of steam per hour is required to heat this air from 91°F. to 118°F.? Ans. 661.5 lb. per hour.

(9) Define: (*a*) absolute humidity; (*b*) relative humidity; (*c*) dew point; (*d*) dry-bulb thermometer; (*e*) wet-bulb thermometer. (*f*) When is air said to be saturated?

(10) The dry-bulb reading is 88° and the wet-bulb reading is 75°. Using the diagram, Fig. 42, find: (*a*) the relative humidity; (*b*) the absolute humidity; (*c*) the dew point. (*d*) If 1230 lb. of this air at 88° were heated to 120°, what would be its volume?

Ans. (*d*) About 18,460 cu. ft.

(11) What is the most practical method for removing the excess moisture from the air, and why?

(12) (*a*) Roughly, how much water is evaporated by the dryers for each ton of paper produced? (*b*) If the paper enters the dryers 71% wet and leaves 92% dry, how many tons of water must be evaporated to produce 28 tons of finished paper? Ans. 60.82 tons.

(13) Why should roofs be well insulated?

(14) Describe some of the methods for recovering the heat from the air leaving the machine room, and state the advantages of doing this.

(15) What are the principal problems encountered in the heating and ventilation of (*a*) the grinder room? (*b*) the machine room?

SECTION 6

GENERAL MILL EQUIPMENT

(PART 4)

LUBRICATION AND WATER

LUBRICATION

BY J. N. STEPHENSON, M. S.[1]

WHY LUBRICATION IS NECESSARY

170. Important to the Mill Man.—The correct lubrication of paper-mill machinery is of vital importance to managers, operators, and owners. The difference between correct lubrication and ordinary lubrication may, in some cases, create the difference between a profitable and an unprofitable operation of the mill. Correct lubrication will increase the productiveness of the mill; it will insure freedom from shut downs due to bearing trouble; it will decrease power losses; it will result in more uniform speed control, thus insuring considerably less broke; it will decrease the cost of repairs; and it will give longer life to the machines.

Correct lubrication is essential if the maximum efficiency is to be obtained from the operation of paper-mill machinery. The saving in repairs and renewals, and the time that is saved by the continuous operation of the machines when properly lubricated, makes it well worth while for everyone interested in the operation of machinery to study this subject seriously. The common methods of applying lubricants to the various parts of machines,

[1] Acknowledgement is made to the Imperial Oil Co. for much information and assistance.

with detailed descriptions of special lubricating devices that may be used to advantage, will now be treated.

171. What Lubrication Does.—Whenever a machine operates, there is a movement of some of its parts; and whenever one of these parts moves, there is friction between this part and the surface it touches. No matter how smooth the two surfaces in contact may be, they are, nevertheless, full of ridges and projecting points, as may be clearly seen when the surfaces are examined under a microscope. By placing a thin film of lubricant, usually oil or grease, between these rubbing surfaces, they are kept from coming into contact with each other; and when the lubricant is the proper one to use for any particular case, the friction is reduced almost to the vanishing point. Ordinary rubbing friction is here changed into what is practically fluid or floating friction.

If a journal were to revolve in its bearing without lubrication, the friction resulting from metal to metal contact would heat the bearing and journal, abrade the metal surfaces, and would increase the power required to drive the machine. The limit is reached when the metallic surfaces *seize*, because of the expansion of the journal, due to the heat, and the cohesion of the particles in intimate contact; this effect is sometimes called *freezing*.

172. Incomplete and Complete Lubrication.—When scant lubrication is introduced between metallic rubbing surfaces, there is a certain amount of friction, heating, and abrasion, depending on the degree to which the surfaces are lubricated; there is also a loss of power, due to the extra power required to drive the machine. It is safe to say that the majority of bearings are improperly lubricated; that is, the rubbing surfaces are not kept completely and continuously apart, which results in more or less wear, and the loss by friction is greater than it should be.

By the positive application of a sufficient quantity of the proper grade of oil, it is possible to form a complete oil film between the rubbing surfaces, and metal to metal contact, with its consequent wear, is eliminated. The only kind of friction then present is the friction within the oil itself, called the *fluid friction* of the oil; and such bearings may be said to be **completely lubricated.** When the particular oil best suited to the oiling system and to the

operating conditions is used, and in just the right quantity, the result may be termed **perfect lubrication.** A perfect lubricating film will be formed, wear will be eliminated, and there will be the lowest possible degree of fluid friction. Perfect lubrication is a big factor in reducing operating costs and in securing continuous operation of the machinery.

173. Lubricating Systems.—There are many methods or systems for applying the lubricant, according to the nature of the lubricant, the conditions under which it is used, etc., the principal ones being the following:

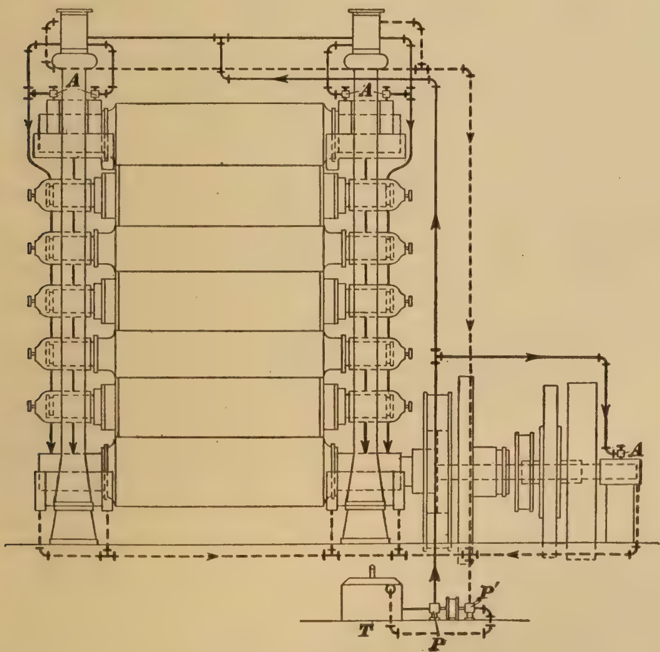

FIG. 44.

Bath Lubrication: The oil is contained in the housing of the bearing, and the bearing surfaces are partly or entirely submerged.

Circulation Lubrication: Oil is circulated through the bearings, drains into a pump, and is returned by the pump, which may supply oil to the bearings direct (under pressure) or by gravity from a head tank through controllable sight-feed adjustments, without pressure. An illustration of this system, as applied to a calender, is shown in Fig. 44. The oil is taken from storage

tank T, through pump P, and is distributed as shown by the heavy full lines. Feed adjusters are indicated at A, and the used oil is returned to the tank by a pump P' or by gravity, as indicated by the heavy dotted lines.

Splash Lubrication: Oil that is contained in an enclosed chamber is splashed to the parts to be lubricated by reason of a moving part of the machine dipping into the oil at frequent intervals. This system is usually applied to engines, the crank pin splashing oil direct to the bearings or into pipes that lead to them.

Ring Lubrication: Oil that is contained in the lower part of the bearing housing, see A, Fig. 45, is carried to the rotating shaft C by the motion of rings, collars, or chains (in this case, the ring B), which dip into the oil and roll or revolve loosely through the motion of the shaft. The oil leaves at the ends of the bearings E and drips into the oil well, to be re-circulated and used again.

Drop-Feed Lubrication: Oil that is contained in individual or multi-feed drop oilers, wick feeds, or bottle oilers is supplied to the bearing at a regulated rate, drop by drop, by gravity, capillary action, or by a siphon. A drop-feed oiler is shown in Fig. 46. The oil is contained in a glass cylinder A, and it drops, visibly, through glass tube T to the bearing. The feed is adjusted by turning the milled nut N. To start the flow, the handle H is raised to the position indicated by the dotted outline; this opens a needle valve in the bottom of cylinder A.

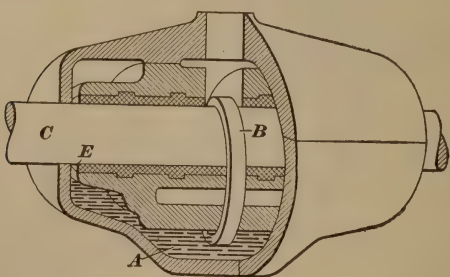

FIG. 45.

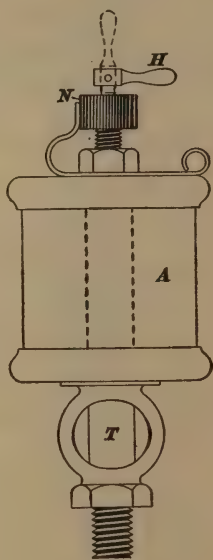

FIG. 46.

Hand Lubrication: Oil from an oil can is supplied to the bearings or surfaces by hand at intervals; in general, this method is either wasteful or insufficient oil is supplied.

Mechanical Force-Feed Lubrication: Oil that is contained in a lubricator (oil container) is forced to the moving parts by one or more plunger pumps that are driven by the engine or machine being lubricated.

Hydrostatic-Feed Lubrication: Oil that is contained in the reservoir of a lubricator is discharged through an oil feed pipe by water displacement. Steam condensation is the usual source of water. As the water (condensed steam) collects in the bottom of the reservoir, the oil rises (being lighter than the water) and is forced out through the system.

Grease Lubrication: Grease is applied by means of specially designed cups, or by hand.

Graphite Lubrication: Plain flake graphite or graphite mixed with oil may be applied by hand or may be fed with the oil.

LUBRICANTS

174. Oils.—Wherever possible, high-grade oils should always be used for bearing lubrication. The superior quality of such oils will insure correct lubrication, and their long life will guarantee the greatest economy in their use. Not only should the oil be carefully refined and compounded, but it must also be exactly suited to the work it is to do; it must be sufficiently fluid at the temperature at which it is used to be readily drawn between the bearing surfaces, and it must have sufficient body to support the load without being squeezed out of the bearing.

175. Greases.—Greases are used occasionally in the lubrication of paper-mill bearings, where, due to the construction of the bearing housing, it is inconvenient or impossible to apply oil economically and efficiently. Only those greases should be used that are of high quality and possess the characteristics that adapt them to the work they are to perform. Whenever possible, the grease should be applied to the bearing surfaces by compression grease cups, which exert a continuous pressure on the grease and force it out of the cup at a steady rate. When bearings are packed with a body of grease in contact with the revolving shaft, the grease should be frequently stirred or turned, so it will not form a skin over the surface. The formation of this skin checks the delivery of the lubricant and may seriously damage the bearing or journal surfaces. All greases are subject to this skin forming

tendency, especially when used in contact with heated journals; but high-grade, carefully made greases exhibit this tendency to a less extent than ordinary greases.

Open gears require grease lubrication. For this purpose, a very viscous grease, one having strong adhesive properties, should be used. It should be a resinous, tarry composition that will adhere to the gear and pinion teeth, and not be squeezed out, rubbed off by heavy pressure, or washed away. It should act as a protective coating to prevent corrosion of the surfaces, and also as a lubricant and as a cushioning agent to absorb shocks. To secure the best and most economical service, this grease should be applied hot. The most convenient, economical, and effective method is to heat the grease slowly, so as not to burn it, until it is quite fluid, and then paint it on the gear teeth with a brush.

176. Graphite.—Graphite, either in the form of flakes or very finely divided (deflocculated), is very slippery and has good lubricating properties. Being a solid, it does not squeeze out under heavy pressure, and it is not affected by high temperatures; it is sometimes mixed with grease or oil for convenient application.

A **hot bearing** occurs when the lubrication is defective, though the real cause may be poor workmanship—as a poor job of lining the bearing with babbitt. To correct this, a little graphite may first be applied, and then a generous amount of oil; the bearing should be watched carefully and the babbitt examined.

If a bearing has begun to cut, further cutting may be prevented by taking out the shaft and polishing the journal with the finest emery cloth and oil, then wiping it clean before returning it to position in the bearing. On reassembling, a little of the finest flake graphite is stirred into some cylinder oil, and the bearing is oiled freely with the mixture. Unless the oil is so thin that the graphite settles, the graphite will aid greatly in protecting the bearing from further cutting.

LUBRICATING DEVICES

177. Bottle Oiler.—The bottle oiler, see Fig. 47, is widely used in the lubrication of paper-mill machinery. It is an inexpensive mechanical device that can be relied on to feed oil at a very slow rate; at the same time, it will insure a continuous supply as long as the shaft rotates. Bottle oilers cannot, of course be installed where they would be in the way of moving parts of

the machine, of work passing through the machine, or of the attendant. Very large bearings may necessitate the use of two or more bottles.

The bottle oiler consists of a glass bottle A, Fig. 47, with a brass cap B having a tube formed at one end, into which is placed a steel spindle C. The spindle fits loosely inside the tube, and its lower end is in contact with the revolving journal D.

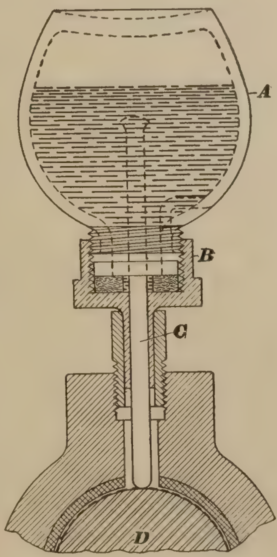

FIG. 47.

178. How the Bottle Oiler Acts.—The bottle being open at one end only is an air-tight container, and it will hold its supply of oil in suspension until air is admitted to the chamber. Air is caused to enter the bottle by reason of the pumping action of the steel spindle C. This spindle, through being in contact with the revolving shaft, is given a slight dithering (trembling, vibrating) action, which has the effect of passing a small amount of air up between it and the sleeve (tube), and into the bottle. The air rises through the oil, expands, and forces out a small quantity of oil. This pumping action of the spindle is so slight that only a very minute quantity of oil is delivered.

The operation of the oiler is automatic, in that when there is no motion of the shaft there will be no dithering of the spindle and, consequently, no discharge of oil. But, whenever the shaft is turning, the spindle dithers, and the bottle delivers its minute quantity of oil continuously and uniformly. When the proper oil is used, this constant minute quantity is sufficient for the complete lubrication of the bearing.

179. Rate of Feeding.—A bottle oiler will feed approximately 4 ounces of oil per month of 300 working hours. This will vary somewhat with the speed of the shaft. In no instance should a bottle oiler run empty in less than two weeks of operation; only in exceptional cases, with extremely slow-speed operation, will one filling last longer than 6 or 8 weeks, assuming the machine to run 10 hours daily.

The ordinary operator or attendant will frequently apply as much oil to a bearing daily as a bottle oiler will feed to it in a month. Bearings require very little oil, but they must be supplied with that little continuously.

180. Hand Oiling.—As the result of hand oiling, the bearing is copiously lubricated for a few minutes, the amount used rapidly decreasing up to the time of the next application. Most of the oil that is supplied by hand oiling runs through the bearings and is wasted, doing no useful work. Mechanical oiling devices eliminate the intermittent application and waste, and they insure the supply of the minimum requisite quantity of oil at all times. When hand oiling is necessary, it should be done sparingly, but frequently.

181. Wick-Feed Oiler.—The wick-feed oiler, Fig. 48, consists of a receptacle *M* in which the oil is contained, and which is provided with channels, pipes, or openings through which wicks may be led to the desired delivery points. These oilers are either single-feed or multi-feed.

One type of wick-feed oiler is designed to supply lubrication to bearings that have the greatest bearing pressure on the cap or upper surfaces. For these bearings, the oil should be fed to the bottom part, where the pressure is least, so the oil may enter the bearing easily and be drawn in between the shaft and the bearing surface. For this reason, the oil container is suspended below the bearing, and the wick extends from the bottom of the oil receptacle up through the bearing shell to the bearing surface. The oil feeds up through this wick by capillary action, the wick acting exactly as in an ordinary kerosene lamp. The action is entirely automatic, and the feeding stops as soon as the machine stops. When the shaft is running, oil is drawn from the wick into the bearing. When the shaft stops, there is no tendency to draw oil away from the wick; although the wick remains saturated with oil, there is no flow. Where the wick bends over an edge, as the edge of a pipe, the edge should be rounded, so as not to shut off the flow.

The most common type of wick-feed oiler is designed to feed oil to the top of the bearing. For this purpose, an oil reservoir *M*, Fig. 48, is mounted above the bearing, and a wick *W* extends from the bottom of the oil receptacle up over a partition, or into the pipe *P*, and down to a point below the bottom of the oil receptacle.

In this type, the capillary action draws the oil up in the wick to the point where it passes over the partition; the oil runs down through the longer leg of the wick, which insures continuous feeding, based on the principle of the siphon. This type is not automatic; the feeding will continue whether the machine is in operation or not as long as the short leg of the wick is in contact with the oil. A stop cock N admits oil or stops its flow to the bearing.

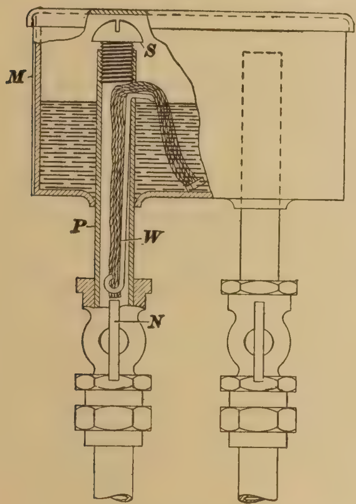

FIG. 48.

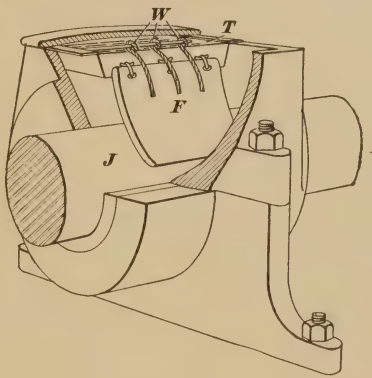

FIG. 49.

182. Regulating the Feed.—There are two methods of regulating the feed or the delivery of oil in the wick-feed oiler. One method consists in changing the size of the wick to suit conditions. Large wicks will feed more oil than small ones; hence, by increasing or decreasing the number of strands in the wick, any desired feed may be obtained.

The second method consists in pinching the wick between two hard surfaces, so as to restrict the oil flow; for example, by turning the screw S, Fig. 48. A wick held loosely between these two surfaces will give a copious flow; but when the pressure on the wick is increased by bringing the surfaces closer together, the flow is decreased. A very close regulation of the flow may be secured in this manner.

183. Another Type.—Another type of wick-feed oiler is shown in Fig. 49; it is known as the tray and pad wick oiler. Oil is put

into the tray T; it is carried by the wicks W to a felt pad F, which distributes the oil over the journal J.

184. Reference Books.—For further information, the reader is referred to the following list of books, which has been taken from Rogers' Manual of Industrial Chemistry:

Archbutt and Deeley: Lubrication and Lubricants.
Holde-Mueller: Examination of Hydrocarbon Oils.
Davis: Friction and Lubrication.
Gill: A Short Handbook of Oil Analysis.
Battle: Lubricating Engineer's Handbook.
Lockhart: American Lubricants.

WATER

By Hervey J. Skinner, S.B.

COMPOSITION AND CLASSIFICATION

185. Water Supply.—The water supply of a pulp or paper mill is one of the essential factors in determining its location. Water is used in nearly all the individual manufacturing operations, and the total amount required for each unit of pulp or paper produced is relatively large. The quality of the water is of primary importance, both as regards the efficiency of the processes and the effect of certain characteristics of the water on the finished product.

In order to appreciate the relation of the water supply to the manufacturing processes and to the finished product, as well as to understand the chemistry of the purification processes that are conducted in nearly every pulp or paper mill, a knowledge of the composition of the various classes of natural waters is essential.

186. Composition of Natural Waters.—In the state in which it occurs in nature, water is never pure. Rain water is, perhaps, the purest form; but even rain water in descending through the atmosphere dissolves carbon dioxide, sulphur oxides, and other gases. Water holding these gases in solution becomes an active solvent for the various minerals that make up the earth's crust, such as calcium, magnesium, iron, aluminum, silicon, sodium, potassium, etc. All water, therefore, contains these elements and, to a less extent, many others, in amounts depending on the character of the surrounding soil and the length of time that the water has been in contact with it. Water also dissolves vegetable matter, and it is a medium for bacteria and animal life; hence, both the organic and inorganic contents must be considered.

187. Classification of Waters.—According to its source, water may be classified, in general, as: (*a*) rain water; (*b*) surface water; (*c*) ground water.

Rain water scarcely needs to be considered, since it is never available in quantities sufficient for manufacturing purposes.

Surface waters include the water from brooks, rivers, ponds, and lakes, and it is these waters that are most used in the pulp and paper industry. These waters contain impurities, according to the nature of the surrounding soils and the springs that oftentimes feed them; they are usually softer, and contain less mineral matter and more organic matter, than ground waters. Suspended matter is often present, and in the case of swampy and peaty surroundings, the waters may be more or less discolored. Surface waters will vary greatly at different times; this is particularly true of river waters, which are influenced by rainfall, drought, and contamination from surface drainage or from mill pollution.

Ground waters are those that come from wells and deep springs; on account of their longer period of contact with the earth's constituents, they generally contain a larger amount of dissolved mineral matter. They are, as a rule, clear, and are free from suspended matter; partly on account of the lower content of organic or vegetable matter, and partly because of the filtering action of the soil.

188. Hard and Soft Waters.—Waters may also be classified in accordance with their composition as **hard waters** and **soft waters.** The constituents that make a water hard are the salts of calcium and magnesium and, to a less extent, other dissolved mineral matter; soft waters are those which are low in these constituents. The hardness of water may be of two kinds, designated as temporary hardness and permanent hardness.

The **temporary hardness** of water is due to the presence of bicarbonates of calcium $Ca(HCO_3)_2$ and magnesium $Mg(HCO_3)_2$. These bicarbonates are held in solution by an excess of carbonic acid. On heating such waters, the bicarbonate is broken down, and carbon dioxide gas passes off, in accordance with the equations

$$Ca(HCO_3)_2 + \text{heat} = CaCO_3 + H_2O + CO_2$$
$$Mg(HCO_3)_2 + \text{heat} = MgCO_3 + H_2O + CO_2$$

The insoluble carbonates of calcium and magnesium are precipitated, thus furnishing an easy means of removing temporary hardness.

Permanent hardness is due to the presence of calcium sulphate $CaSO_4$, calcium chloride $CaCl_2$, and magnesium sulphate $MgSO_4$; these can be removed only by chemical methods of water softening.

CHARACTERISTICS OF WATER FOR PAPER MAKING

189. Qualities that Affect Paper Making.—The principal qualities of water that determine its suitability for pulp- or paper-mill purposes are: (*a*) color; (*b*) the suspended matter; (*c*) the presence of iron; and (*d*) hardness or an excessive amount of dissolved mineral matter.

Water of uniform composition and temperature is also desirable, but these are conditions over which there is little control. Surface waters, for example, are influenced considerably by rainfall, drought, and the trade wastes that are discharged into them. The variation in temperature from freezing in winter to around 70° to 80°F. in summer causes variable manufacturing conditions. Plant and bacterial growth during the summer months is often the cause of annoying difficulties. Ground waters are, as a rule, more constant in composition and temperature throughout the year than surface waters, and are to be preferred, all other conditions being equal. The temperature of a water is an important factor where it is to be used for cooling purposes.

190. Color.—Water having little or no color is essential for the manufacture of any paper, except papers of inferior quality in which color and appearance are of no account.

Pure water is colorless; but almost all natural waters, except sometimes those from deep wells and springs, have some color. In surface waters, all variations in color are found, ranging from almost colorless to a deep brown or red. The color of water is generally due to dissolved organic matter derived from decaying vegetation, or to iron salts. The color may be removed or, at least, greatly improved by filtration, a subject that will be discussed later. The amount of color permissible depends entirely on the product to be manufactured.

191. Suspended Matter.—Suspended matter is troublesome in the manufacture of paper or pulp because it becomes entangled in the fibers, which act as a very efficient filter, thus causing spots and other imperfections in the finished product. Suspended matter nearly always is colored, so that its effect is closely connected with that of dissolved coloring matter.

The amount of suspended matter varies over wide limits, particularly in river waters, where it is influenced by the rains, which wash finely divided soil, leaves, and other foreign matter into the streams. Sewage and mill effluents, both of which are

commonly discharged into rivers, also contribute to the suspended matter of surface waters.

Filtration of the water removes the suspended matter and may improve the color. The more complete removal of color and of iron is accomplished by the chemical treatment of the water before filtration. This is an essential process in order to obtain a clean and colorless supply.

192. Iron in Water.—The presence of iron in water is most objectionable, since cellulose has the property of adsorbing[1] iron and other metals, from dilute solutions. In the pulp- and paper-making processes, the cellulose is constantly in contact with the water, which is a dilute solution, and iron, if present, will therefore be adsorbed. This adsorption of iron results in a yellowing in the case of white papers, and in a dulling of all shades with colored papers, particularly the more delicate ones.

Iron is especially troublesome in photographic papers: it is claimed that deterioration of sizing in papers that have been exposed to light is related to the iron content of the paper.

193. Forms in Which Iron Occurs in Water.—Iron may be present in water in both the ferrous and ferric condition. In the case of ground waters, iron is usually in solution as ferrous carbonate $FeCO_3$. The iron present in the soil is generally combined as ferric oxide Fe_2O_3, and in this form is insoluble in water. If the water contain dissolved organic matter in appreciable amounts, the iron is reduced from ferric oxide to ferrous oxide FeO; this combines with carbonic acid to form ferrous carbonate, which is soluble and goes into solution. When such waters come to the surface and are exposed to the air, oxidation takes place; the ferrous carbonate is decomposed, and is converted to ferric hydrate $Fe(OH)_3$, which is insoluble.

In surface waters, the iron is nearly always present as hydrated ferric oxide, colloidally dispersed, although cases are known where trade wastes, such as pickling liquors from steel mills, are responsible for the presence of ferrous iron in streams.

194. Removing Iron.—The removal of ferric iron is accomplished by the ordinary methods of coagulation and filtration; while in the case of waters containing ferrous iron, oxidation with chemicals, or aeration, is resorted to. Aeration can be carried out

[1] Attracting to its surface; causing to adhere to its surface.

by blowing air into the water, or by allowing water to flow over beds or towers filled with coke, which present a large surface of water to the oxygen of the air. Some waters contain iron in such a form that it apparently cannot be removed by simple aeration and filtration, but such cases are not common.

195. Crenothrix.—Crenothrix, or "iron bacteria," are organisms that sometimes cause trouble in mills using unfiltered water from ponds. These organisms consist of cells, united end to end to form filaments or threads. They require ferrous iron for their existence, drawing it from the water and depositing it as ferric oxide around the filaments. Light is not essential for the growth of this organism; in fact, it thrives best in dark places, such as tanks and pipes, where accumulations form; these latter break away, causing iron spots in the product. Crenothrix may be removed and kept out of the water supply by efficient filtration.

196. Amount of Iron Permissible.—The amount of iron permissible in water used for paper making depends on the product to be manufactured. For high-grade papers, where color is a primary consideration, water that contains less than 0.1 part of iron per million parts of water is desirable, although some high-grade writing-paper mills are operating satisfactorily with water whose iron content ranges from 0.1 to 0.2 part per million.

HARD WATERS

197. Effects of Hardness on Pulps.—It is a distinct disadvantage to use hard water in washing pulp, particularly sulphite pulp, since insoluble calcium and magnesium resinates are formed; these deposit on the fiber, making subsequent bleaching difficult. In the soda-pulp process, hard waters are also objectionable, since calcium and magnesium salts are precipitated by the caustic soda and carry down coloring matters that are also difficult to bleach. For these reasons, the use of soft water is much to be preferred. In the coloring of paper, soft water is also desirable, since the carbonates cause precipitation of the salts that are ordinarily used as mordants.

198. Effects of Hardness on Sizing.—Hard waters are troublesome when sizing with rosin; the mineral salts react with the size, forming insoluble resinates, which have no sizing action.

Furthermore, according to Tucker,[1] the salts present in the water affect the colloidal condition of the size, tending to make the rosin gather into large particles, thereby reducing their covering power.

The difficulty of sizing with hard waters can be overcome to some extent by increasing the proportion of alum; although, in the case of exceedingly hard waters, it is sometimes almost impossible to obtain any sizing effect, regardless of the amount of size or alum used.

Tucker[2] claims that rosin size has a selective action and precipitates with alum, rather than with calcium and magnesium salts; it is for this reason that alum is sometimes added to the furnish before the rosin size. The use of protective colloids, such as glue or casein, has been suggested as a remedy for the difficulties of sizing with hard waters.

199. Effects of Hardness on Scale Formation.—Hard waters are also objectionable because of the tendency to form scale wherever they are constantly in contact with metal parts, such as pumps and the wet end of the paper machine. This scale has a tendency to break away, and causes endless trouble. When machine wires become coated with the scale, frequent scouring with acid is necessary, which greatly shortens the life of the wires.

200. Soft Water Not Essential.—While soft waters are more desirable, they are not absolutely essential; excellent papers are made with hard water that meets the other requirements of freedom from iron, color, and suspended matter. The Berkshire Hills district of Western Massachusetts furnishes a fine example of the manufacture of high-grade paper of the finest quality with relatively hard water. In another instance, in a different locality, a mill is actually producing book paper of high quality with a very hard water, one containing as high as 700 parts per million of solid matter.

AMOUNT OF WATER REQUIRED

201. Sources of Supply.—The amount of water used by pulp and paper mills varies over wide limits. Many mills are located on streams where there is an abundant supply; and it may in such

[1] Paper Trade Journal, May 3, 1923, p. 47. See also Vol. III, Section 1, *Preparation of Rags and Other Fibers;* Section 4, *Loading and Engine Sizing;* and Section 5, *Coloring.*

[2] Paper Trade Journal, May 3, 1923, p. 47.

cases with some truth be said that the stream is shunted through the mill. Other mills draw their supply from wells or small streams, where the supply is limited, especially at certain periods of the year.

In many cases, no records are kept of the water used; and where no data are available, it is usually estimated from the capacity of the pumps, and represents the total requirements of the mill.

202. Variations in Amount Used.—No two mills are alike in respect to their operations; for example, a book-paper mill may cook its own wood pulp, or it may purchase all or a part of its pulp requirements. Similarly, the water used in a writing-paper mill will vary according to the proportion of rag fiber and wood pulp used.

Many mills, in fact, most mills, that make groundwood, unbleached sulphite, and kraft pulp, and, to a less extent, those making bleached pulp, use a large amount of white water for their showers, thus reducing the consumption of fresh water.

203. Use of White Water.—The use of white water is sometimes objected to, particularly in paper mills, on account of the accumulation of slime that may result; and, oftentimes, the water, after running through a save-all to recover the fiber, is allowed to go to waste. In general, it may be true that water which has once served its purpose is not suitable again for the same purpose; but, on the other hand, water undoubtedly can be used over again as white water to a much greater extent than is practiced in American mills. If, after continued use, it becomes foul, it may be discarded; or if the supply be very limited, it may be treated by coagulation and filtration, and made as good as the original supply. Refiltration is being given consideration in the design of new filter plants; and it will unquestionably be used more in the future, especially in locations where the water supply is limited.

204. Approximate Amounts of Water Used.—Table IV gives the approximate amounts of water required in the manufacture of various kinds of wood pulp. These are not actual operating figures, but are estimates frequently used in calculating the approximate water requirements for new installations. The figures given in the table may be considered as maximum amounts; they may be materially reduced if a mill is designed and operated with a view to economy of water.

TABLE IV

Gallons of Water per Ton of Bleached Soda Pulp

Part of Process	Groundwood	Unbleached sulphite	Bleached sulphite	Bleached soda	Kraft
Wood preparation....	5,000	10,000	10,000	5,000	10,000
Liquor making.......	......	30,000	30,000	35,000	35,000
Fiber preparation....	......	15,000	15,000	15,000	15,000
Bleaching..........	......	....	30,000	30,000	....
Machine operation...	10,000	10,000	10,000	10,000	10,000
Fresh-water showers..	25,000	30,000	35,000	35,000	25,000
Steam and power.....	Hydraulic	15,000	15,000	15,000	15,000
Miscellaneous........	10,000	5,000	5,000	5,000	5,000
Totals.............	50,000	115,000	150,000	150,000	115,000

205. Some Special Operating Figures.—Figures obtained by the author from pulp mills in different parts of the United States show the following amounts of water used per ton of pulp as typical operating figures:

	Gallons
Groundwood..................................	21,000
Unbleached sulphite..........................	60,000
Bleached sulphite............................	80,000
Bleached soda................................	100,000

The author has been unable to secure any actual operating figures for the cooking of rags, but the amount of water required has been variously estimated at from 150,000 to 200,000 gallons per ton of rag paper.

More accurate data are available concerning the amount of water used in the conversion of pulp to paper. For mills using either the Fourdrinier or the cylinder machine, 30,000 to 40,000 gallons per ton of paper is a reasonable amount. This figure can be reduced by the re-use of white water; in fact, in one instance, the writer has a figure as low as 15,000 gallons per ton of book paper.

MECHANICAL TREATMENT OF WATER

206. Methods of Purifying.—In order to insure a supply of water of uniform quality, it is necessary in the case of nearly all pulp and paper mills to resort to some method of purification.

In certain special cases, however, when a mill has an exceptional supply of ground water, or in mills making an inferior product, raw water is sometimes used without any treatment.

Filtration, either with or without previous chemical treatment, is the most common method used in the treatment of water; it will remove suspended matter and also color due to ferric iron or organic matter. It is not usually practical to attempt to soften water used in manufacturing operations by chemical methods, since the great amount of chemicals required makes the cost prohibitive. In the case of mills using exceptionally hard waters, chemical treatment of the boiler feed water is advisable; and the use of softened water in certain details of the process, such as size making, may then be justified.

207. Filtration.—The filtration of water for pulp and paper mills is done in sand filters. The English, or slow sand, method of filtration has been quite generally superseded by rapid, or mechanical, filtration, sometimes called the American system. **Slow sand filtration** is still practiced in some instances for the filtration of public water supplies; but **mechanical filtration** is better suited to pulp- and paper-mill purposes on account of the economy of space, and also because it is more efficient in removing iron and color.

Mechanical filters are of two general types, gravity filters and pressure filters.

208. Gravity Filters.—The gravity filters consist of open tanks, made of wood, steel, or concrete, and filled with a filtering material, through which the water flows by gravity. The filtering material generally consists of a bed of graded gravel, placed in the bottom of the filter to a depth of 9 or 10 inches, on top of which is a bed of filtering sand that is usually about 3 feet in depth. The gravel varies in size from $\frac{1}{8}$ inch to 1 inch; it is usually screened to three or four different sizes, the coarsest being placed on the bottom, around the strainers, and graded up to the smallest size, upon which the sand rests. The gravel should be of a hard and durable variety, free from limestone, loam, and fine dirt. The sand should be a hard silica sand, of a uniform size of about 0.5 millimeter diameter. On the bottom of the filter, there is a main header pipe, with lateral pipes extending to the sides of the beds. Brass strainers or sand valves are screwed into these lateral pipes and are distributed over the bottom of the filter, so as to insure uniform filtration as well as

equal distribution of wash water. This screening system is either filled in with large gravel or is sometimes embedded in concrete.

On reaching the filter, the water passes down through the bed of sand and out through the strainer system into a clear-water basin, from which it is pumped to the place where it is to be used. In many plants, the supply of filtered water is drawn direct from the filters; but this method has the disadvantage of irregular operation of the filters. Sand may also be sucked out of the filters in such cases, necessitating careful straining of the water at the point of use. It is better practice to install a storage tank for filtered water; this acts as a balance in the system and takes care of peak loads, at the same time insuring a uniform rate of filtration, which is essential to efficient operation.

209. Pressure Filters.—In the pressure type of filter, the principle is the same as in the gravity filter, except that closed steel tanks containing the filtering medium are used. The water is pumped from the source of supply through the filters, under pressure, direct to the distributing points. The chief advantage of the pressure filter is that it can be installed on any pressure line, without double pumping equipment, which is generally necessary with the gravity filter.

210. Use of Aluminum Sulphate.—In mechanical filtration, aluminum sulphate $Al_2(SO_4)_3$ is added as a coagulant to the raw water before it enters the filter. The aluminum sulphate reacts with the calcium carbonates and forms aluminum hydrate $Al(OH)_3$, which is gelatinous in character; with the suspended matter that becomes entangled with it, it forms a layer on the top of the sand, which offers a closer and most compact medium for holding back the finer particles.

After receiving the aluminum sulphate, the water usually passes through sedimentation basins, so as to give time for the aluminum hydrate to *coagulate* and entrain the suspended matter. The basins vary in size, depending on the amount of water to be filtered and the time required for proper coagulation, which varies from 30 minutes to 3 or 4 hours, according to the character of the water. Sedimentation basins may be used with pressure filters, but this is seldom done, since waters that require sedimentation are usually treated more successfully in gravity filters.

211. Use of Soda Ash.—If the water does not possess sufficient alkalinity to react with the aluminum sulphate, soda ash or lime is also added, to effect the desired coagulation. Sodium aluminate has also recently come into use for this purpose. The amount of aluminum sulphate required usually varies from $\frac{1}{4}$ to $\frac{1}{2}$ grain per gallon to 3 or, sometimes, 4 grains per gallon, depending on the degree of turbidity, amount of sediment, and the color of the water. When dissolved iron is present, it must be precipitated, either by the addition of milk of lime or by aeration in connection with the alum treatment.

The chemicals may be added dry through specially designed feeding devices, or solutions may be prepared in tanks and fed into the raw water at the point of entrance to the sedimentation basin. These solutions are best added through automatic feeding devices, which are controlled by the amount of raw water passing to the sedimentation basin.

The older method of controlling the proper amount of chemicals by determining the alkalinity, using methyl orange as an indicator, has been largely superceded by controlling the hydrogen-ion concentration, using brom-thymol-blue as an indicator.

Individual waters have a fairly definite and limited range of hydrogen-ion concentration at which coagulation takes place most effectively (see Appendix, Section 4). This should be determined experimentally for each water to be treated.

212. Cleaning the Filter.—After a filter has been in operation for some time, it becomes clogged with accumulated sludge, and the rate of filtration is very much decreased. The filter is then cleaned by washing; and the principal difference in the various makes of mechanical filters is in the method of washing. All types are washed by reversing the flow of water; that is, by passing the water up through the bed of sand and allowing it to overflow into the wash gutters, which are located along the sides of the top of the filters. Sand-guard boards running around the top of the filter prevent the sand from being washed out.

There are various methods employed for breaking up the layer of sand, which becomes more or less compacted and clogged with sediment from the water. In some filters, a revolving rake is used for stirring up the sand layer; but the **air-wash** system, which consists of blowing compressed air up through the filter bed during the washing process, is preferred by many, on account of its simplicity and freedom from moving parts.

The amount of wash water required should be at least 10 gallons per minute per square foot of filtering area, supplied at a pressure of about 10 pounds at the filter outlet. The amount of air required is at the rate of 4 to 5 cubic feet per square foot of filtering area, at a pressure of 5 to 10 pounds. It is important that the air pressure be so regulated that the sand will not be washed away. The proper pressure for any filter may be determined by catching some of the wash water and examining it for sand. In general, the greater the pressure the better, provided the sand is not washed away.

In some filters, a separate system of piping is used for the air; but in the more modern filters, the air and water for washing are forced back through the strainer system. By the use of the air-wash system, a saving of 35% to 50% in the amount of wash water is effected.

213. Size of Filter.—Mechanical filters are built in various sizes and shapes, according to the individual requirements of the mill and the condition of the water. The generally accepted capacity for gravity filters varies from 2 to 3 gallons per minute per square foot of filtering area. In pressure filters, the rate of filtration is a little higher; but the filtering area should be of such size that the rate of filtration will not exceed $3\frac{1}{2}$ gallons per minute per square foot of filtering surface.

CHEMICAL TREATMENT OF WATER

214. Troubles Caused by Impurities in Feed Water.—The chemical treatment of water for a pulp and paper mill is not, as a rule, economically feasible, except in the case of water used for boiler feeding. When water is heated under pressure and concentrated by evaporation, as in a steam boiler, the dissolved matter goes out of solution and solidifies, either as a hard scale or a soft sludge, depending on the character of the water. These deposits are poor conductors of heat, and they cause fuel losses that are out of all proportion to their thickness; if allowed to accumulate, such deposits will shorten the life of the boiler, and may even cause boiler explosions.

The troubles caused by impurities in boiler feed water are: (*a*) boiler scale; (*b*) priming or foaming; (*c*) corrosion or pitting.

215. Why Impurities Cause Trouble.—The impurities that cause boiler scale are, mainly, the salts of calcium and magnesium, although other dissolved solids may be found in the scale.

Priming or **foaming** results from suspended matter or, more often, from the presence of a relatively large proportion of dissolved substances, which modify the surface tension of the water. Sodium or potassium salts are the principal substances that cause priming, since they remain dissolved, while the greater part of the other salts are precipitated. Foaming permits the passage of water with the steam, thus giving rise to wet steam conditions.

Corrosion or **pitting** is caused by free acid in the water, or by changes that result in liberation of acid within the boiler during evaporation.

The three remedies for boiler-water trouble are: (*a*) water softening by precipitation methods; (*b*) water softening by zeolite filters; (*c*) boiler compounds.

216. Precipitation Methods.—Precipitation methods may be divided into two general classes: first, cold chemical precipitation, followed by sedimentation; second, the application of heat, with or without chemicals, followed by filtration. The object of the cold precipitation methods is to remove those ingredients that form scale, particularly the salts of calcium and magnesium, and to neutralize those which cause corrosion. Various chemicals have been proposed and used as precipitants, but sodium carbonate and lime are those most commonly employed.

217. Softening Water by the Lime-Soda Process.—The lime-soda process, as it has come to be known, is carried out in a water softener, which consists essentially of a settling tank of a size sufficient to give the water the proper period of sedimentation between the time the raw water receives the softening solution on entering the tank and the time it passes out of the overflow pipe. The required amounts of lime and soda are dissolved and fed to the raw water, and are automatically controlled by the flow of water to be treated.

The degree of sedimentation varies; in some types, it is fairly complete, whereas in others, only partial sedimentation is obtained, followed by filtering through coke, sawdust, sand, or any material that will permit filtration at a rapid rate. The accumulated sludge that collects in the bottom of the softener is removed by washing or blowing out.

The various types of precipitation water softeners on the market differ from one another in the design of the tank, the precipitants used, and the method of feeding them; the filtering medium, and other details are also different.

218. Softening Water by Applying Heat.—The water-softening methods that depend on the application of heat are usually conducted in feed-water heaters. While such heaters are designed primarily for the purpose of utilizing waste heat and for raising the temperature of the boiler-feed supply, many are designed to take advantage of the reactions that occur in them. Upon heating, the bicarbonates of calcium and magnesium give off a part of the carbonic acid that holds them in solution, and the insoluble carbonates of calcium and magnesium are precipitated. (See Art. **188.**)

Feed-water heaters may be operated at atmospheric pressure or at or near boil ng pressure. Open heaters are better adapted for water purification. The dissolved gases and the carbon dioxide from the bicarbonates are expelled, and the iron, alumina, and a part of the magnesium and calcium, are precipitated. The precipitation can be made more complete by the addition of soda ash. The water is usually passed through a rough filter of excelsior or coke, to remove the precipitated matter.

In the closed, or pressure type, heaters, some precipitation takes place; but they are not so efficient as open heaters, as there is no opportunity for the gases to escape.

219. Zeolite Softeners.—The zeolite method of water softening is quite different in principle from the precipitation softeners. **Zeolites** are crystalline bodies composed of silica, alumina, and sodium, and have the property of exchanging a part of their sodium for the calcium and magnesium of the water.

A zeolite softener consists essentially of a pressure-type filter, whose filter medium is made up of zeolite instead of sand. The water is passed through the filter, the calcium and magnesium of the water combining with the zeolite and remaining in the filter, while the sodium of the zeolite passes into the water. The reactions that take place are represented by the following equations:

$$Na_2Al_2Si_2O_8 + CaCO_3 = CaAl_2Si_2O_8 + Na_2CO_3$$
$$Na_2Al_2Si_2O_8 + MgCO_3 = MgAl_2Si_2O_8 + Na_2CO_3$$

When the zeolite becomes saturated with calcium and magnesium, the filter bed can be regenerated by passing a solution of common salt through the filter, when the reverse action takes place, thus:

$$CaAl_2Si_2O_8 + 2NaCl = Na_2Al_2Si_2O_8 + CaCl_2$$
$$MgAl_2Si_2O_8 + 2NaCl = Na_2Al_2Si_2O_8 + MgCl_2$$

Zeolite softeners are the only ones that will produce water with zero hardness; but, on the other hand, they have the disadvantage of increasing the concentration of sodium salts, with possible resultant trouble from priming.

220. Boiler Compounds.—Boiler compounds are used more or less extensively for remedying the troubles caused by water in steam boilers. A great variety of materials has been proposed and used as ingredients of boiler compounds. They may be divided into two classes: first, those of which soda ash is typical, and which neutralize any acids and precipitate certain of the scale forming ingredients; second, those that by reason of their colloidal properties prevent the precipitated water from forming into a hard, compact scale.

If a water is hard enough to be objectionable in the boiler, the best method of treating it is through the installation of proper water-softening equipment. It is seldom that the use of boiler compounds can be justified; particularly, since a steam boiler is an expensive piece of equipment, designed for the generation of steam and not for use as a water softener. Furthermore, no boiler compound is of universal application—any more than are patent medicines.

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GENERAL MILL EQUIPMENT

(PART 4)

EXAMINATION QUESTIONS

(1) (*a*) What are the advantages to be derived from correct lubrication? (*b*) Why is a hot bearing undesirable?

(2) Explain how a lubricant acts to reduce friction.

(3) (*a*) What are the principal systems of lubrication? (*b*) Which system and what kind of lubricant would you consider best adapted to the journals of a fast running machine that is subject to considerable vibration and frequent jars and is not frequently inspected? why?

(4) (*a*) Under what conditions should grease be used as lubricant? (*b*) Why is oil usually preferred to grease? (*c*) What great advantage is possessed by graphite?

(5) Describe a bottle oiler and explain how it acts.

(6) Why is mechanical oiling superior to hand oiling?

(7) Describe one type of wick-feed oiler; explain why it is or is not automatic in action.

(8) (*a*) Why is an unfailing supply of water of proper quality so important to a pulp or paper mill? (*b*) Mention the qualities of a good water for pulp and paper manufacture.

(9) (*a*) How does water become contaminated? (*b*) How do impurities in water affect its use in the pulp and paper industry?

(10) (*a*) Distinguish between hard water and soft water; (*b*) between permanent hardness and temporary hardness. (*c*) How may water that is temporarily hard be softened?

(11) Discuss the causes and effects of color in water.

(12) What is the effect of suspended matter in the water supply, and how is it eliminated?

(13) (*a*) Describe the effects of iron in water. (*b*) In what forms does iron occur in water? (*c*) How is it eliminated? (*d*) How much iron is allowable in water for paper making?

(14) (*a*) What are crenothrix? (*b*) How do they affect water? (*c*) What conditions affect their growth?

(15) What effects are produced in pulp and paper making by hardness of water?

(16) (*a*) What is accomplished by the filtration of water? What effects are produced by the use of (*b*) aluminum sulphate, and (*c*) soda ash in the raw water before filtering?

(17) (*a*) Describe how filters are cleaned. (*b*) How much wash water should be used? (*c*) How is the sand kept from washing out? (*d*) What are the advantages of the air wash, and how much air is required?

(18) (*a*) What troubles do impurities in boiler feed water cause, and why? (*b*) how may they be remedied?

(19) Describe the softening of water (*a*) by the lime-soda process; (*b*) by application of heat.

(20) (*a*) What are zeolites? (*b*) Describe the zeolite process of softening water. (*c*) Compare the results of this process with those obtained by other methods of softening water.

SECTION 6

GENERAL MILL EQUIPMENT

(PART 5)

By George C. Bearce, B.S.

STEAM AND ITS USES

INTRODUCTION

221. Reasons for Using Steam.—The heat-carrying capacity of steam, coupled with the fact that it can be compressed and expanded, makes it an efficient agent for transmitting energy. As a conveyor of heat energy, steam is used in the paper industry for process work, such as paper drying, the cooking of chips, old papers, rags, etc., and to make the various kinds of pulp. It is also used to heat and condition the air in the machine room and other parts of the mill, and to heat stock, liquids, chemicals, and other materials used in the manufacture of paper. Steam is also required to drive prime movers, such as steam engines and turbines, and to operate pumps, fans, compressors, stokers, and other equipment. Where mills generate their own electricity for power purposes, the turbo-generator is a large consumer of steam, and the power thus derived supplements steam to a great extent in the operation of many machines.

The first step in making steam is to heat water to the boiling point, the temperature of which is 212°F. when the atmospheric pressure is 14.7 pounds per square inch. At this stage of temperature and pressure, any further application of heat will not increase the temperature, but it gradually changes the water from a liquid to a vapor (gas), and there will be no increase in temperature or pressure until *all* the water has been changed into vapor, i.e., vaporized, in which condition it is called **steam.**

At this point, it will be well to give a few definitions, all of which may be found in *Physics*, Vol. I, but are here repeated for convenient reference.

222. Some Definitions.—The **unit** of heat is one **British thermal unit** (1 B.t.u.), which is the amount of heat required to raise the temperature of 1 pound of water from 63° to 64°F. or, roughly speaking, to raise the temperature of 1 pound of water 1°F.; its *mechanical equivalent*, is 778 foot-pounds of work.

Another unit quite frequently used in connection with metric measurements is the calorie, 1 **calorie** being the amount of heat required to raise the temperature of 1 kilogram of water from 17° to 18°C.; its mechanical equivalent is 427 meter-kilograms of work. One calorie (1 cal.) = 3.96832 B.t.u.

Unless otherwise stated, all temperatures used hereafter will be in degrees Fahrenheit, and the word Fahrenheit or its abbreviation F. will be omitted; thus 65° means 65°F.

The **specific heat** of a substance is the amount of heat required to raise the temperature of a unit weight of the substance 1°, divided by the amount of heat required to raise the temperature of the same weight of water 1°, both at some specified temperature. Since the specific heat is a ratio, by definition, its value is the same in the metric or any other system. While the specific heat of water varies slightly between 32° and 212°, it is always considered to be 1 in practical calculations; hence, the specific heat of any substance may be roughly defined as the number of B.t.u. required to raise the temperature of the substance 1°. Further, if the specific heat of a substance be denoted by c, its weight (in pounds) by w, and the difference in temperature before and after heating (or cooling) by t, the number of heat units u (in B.t.u.) required to heat the body $t°$ (or given off in cooling $t°$) is

$$u = cwt.$$

For further discussion of specific heat, see *Physics*, Vol. I.

The **sensible heat** of a substance is the heat used in raising the temperature of the substance; for instance, the heat used in raising the temperature of water from 32° to 212° is sensible heat. In practical calculations pertaining to water, it is equal to the temperature minus 32°. Thus, if the temperature is 76°, the sensible heat is 76 − 32 = 44 B.t.u. This is not quite exact because of the variation in the specific heat of water, but it is sufficiently accurate in practice.

Latent heat may be explained as follows: When a substance changes its state through application of heat (as from a solid to a liquid, or from a liquid to a gas), heat is required to effect this change, and the amount of heat so used does not show on the thermometer; this heat is called **latent heat.** For example, the amount of heat required to change water at 212° into steam at 212°, both at atmospheric pressure (14.7 pounds per square inch), is 970.4 B.t.u., and this is called the latent heat of evaporation (or vaporization). The latent heat of evaporation (of water) steadily decreases as the pressure (and temperature) increases; it has a definite value for every pressure (temperature), as shown by steam tables.

223. Producing Heat.—The heat required to generate steam is supplied by the combustion of solid, liquid, or gaseous fuels; also, in some cases, by passing an electric current through a medium that offers high resistance to its passage. Fuels are all composed of definite chemical compounds, and their combination with oxygen causes the evolution of heat, the phenomenon being known as **combustion.**

Coal, the most important solid fuel, is made up of uncombined carbon, called *fixed carbon*, a combination of hydrogen and other gases, called *volatile matter*, and incombustible matter (ash) and water. Small amounts of sulphur may also be present. After making a chemical analysis of a coal, the number of B.t.u. that may be obtained from the combustion of 1 pound (called its *calorific value*) may be calculated by means of the following formula, due to Dulong:

$$\text{B.t.u.} = 14{,}600C + 62{,}000\left(H - \frac{O}{8}\right) + 4050S$$

in which C = percentage of carbon (total), H = percentage of hydrogen, O = percentage of oxygen, and S = percentage of sulfur. This formula assumes that the oxygen in the coal is combined with a part of the hydrogen to form water, and the remainder of the hydrogen is available for combustion along with the carbon and sulphur. Thus, suppose an analysis of a certain coal gave the following: $C = 81.35\%$, $H = 3.08\%$, $O = 5.06\%$, and $S = 0.60\%$; then, the heat value by the above formula would be $14{,}600 \times 0.8135 + 62{,}000\left(0.0308 - \frac{0.0506}{8}\right) + 4050 \times 0.006 = 13{,}420$ B.t.u. per pound.

This formula is necessarily somewhat approximate and should be used only when it is not feasible to determine the heat value of the coal calorifically.

224. Air Required for Combustion.—Since the oxygen used in combustion is supplied from the atmospheric air, which is a mechanical mixture of approximately 23% oxygen and 77% nitrogen by weight, the amount of air theoretically required for the complete combustion of 1 pound of coal can be found quite closely when the chemical constituents of the coal are known. Thus, let

W = the weight of air for complete combustion of 1 pound of coal;

C = the weight of the carbon in 1 pound of coal;

$H - \frac{O}{8}$ = the available hydrogen in 1 pound of coal;

then,

$$W = 11.52C + 34.56\left(H - \frac{O}{8}\right)$$

This formula assumes that all the carbon is burned to CO_2, and it takes no account of the small amount of air required to burn the sulphur. In actual practice, it is necessary to use a much larger amount of air than is theoretically required, since it is impossible for the minimum amounts of oxygen and carbon to unite and form CO_2; an excess of air is always required, and the formula merely gives the absolute minimum.

225. Ash and Moisture.—In the boiler house, two important factors in the combustion of coal are the amounts of ash and moisture in the coal. Ash is the non-combustible matter in the coal; it not only gives off no heat, but also it takes heat to raise its temperature to that of the fire, and this is lost. The moisture must be evaporated from the coal while burning, and this also absorbs heat in the combustion process, which is likewise lost. Thus, both ash and moisture decrease the heat values of the coal "as fired," that is, as used.

Oil, gas, wood refuse, bark, and other fuels are frequently used to produce heat by their combustion; they have varying proportions of carbon, hydrogen, and other elements. These fuels also unite with oxygen in a definite chemical union, similar to that just described in connection with coal.

226. Steam.—**Dry saturated steam** is steam in contact with the water from which it was formed (i.e., it has the same temperature and pressure as when it was formed) and which contains no free particles of water in it. As the water gradually turns into steam in an enclosed space, as in a boiler, the pressure gradually increases as the amount (weight per cubic foot) of the steam increases; and the temperature also increases. For dry saturated steam, there is a definite temperature for every pressure; thus, for a pressure of 150 pounds per square inch, absolute,[1] the temperature is 358.5°F.

Wet steam is saturated steam that is accompanied by water particles entrained in it. The volume of water (moisture) in the steam divided by the total volume of the steam is called the **quality** of the steam; it is usually expressed as a per cent. Nearly all saturated steam has a certain percentage of moisture; but in practice, this is disregarded if it does not exceed 1% to 2%.

The **specific volume** of steam (or any substance) is the volume (in cubic feet) of 1 pound of it. The specific volume decreases with the pressure; and for every pressure there is a definite specific volume. Therefore, when steam is expanded in an engine or turbine, there is a change in pressure, and it is this combined change in volume and pressure that causes the production of work (energy).

Superheated steam is steam that is not in contact with the water from which it was formed, and which has been further heated; its temperature is higher than that of dry saturated steam of the same pressure. For example, if the pressure of dry saturated steam be 180 pounds per square inch, absolute, its temperature is 373.1°, its specific volume is 2.533, and its total heat is 1196.4 B.t u.; the same steam superheated 100° and having the same pressure, has a specific volume of 2.96, and its total heat is 1254.3 B.t.u.

227. Comparison of Boiler Performances.—Since the temperature of the feed water and the temperature at which the steam is formed (and also the pressure of the steam) are different for each

[1] A column of air 1 inch square extending indefinitely upward from the earth, measured at sea level, weighs 14.7 pounds. This is called **atmospheric pressure**, and is zero on a pressure gauge. True zero pressure is, therefore, 14.7 pounds below this point, and **absolute pressure** is 14.7 plus gauge pressure. Pressures less than 14.7 absolute or zero gauge come in the range of vacuum; the vacuum gauge reads higher as the pressure falls. An absolute pressure of 150 pounds per square inch is 133.3 pounds gauge. Unless otherwise mentioned, gauge pressures are used.

boiler installation, it is necessary to reduce these to a common basis. The standard way of doing this is to assume that the pressure is 14.7 pounds per square inch; that the temperature of the feed water is 212°; and that the water is evaporated, i.e., changed into steam, at 212°. In common parlance, this is expressed by saying that the steam is formed "from and at 212°." If the steam pressure is greater than 14.7 pounds per square inch (i.e., if the temperature is greater that 212°), and if the temperature of the feed water is less than 212°, as is usually the case, then it is necessary to apply a correction, called the **factor of evaporation,** which is computed as follows:

Let H = the total heat of the steam at the pressure at which it was generated;

t = the temperature of the feed water, which for practical purposes may be assumed to be the sensible heat of the steam; then

$$\text{factor of evaporation} = \frac{H - t + 32}{970.4}.$$

In order to use this formula, it is necessary to use a steam table, one similar to that given in Vol. III, or else a table of factors of evaporation for different values of pressure and temperatures of feed water. The steam table most commonly used at the present time is that of Marks and Davis, published by Longmans, Green & Company. Goodenough's tables are later and also widely used.

228. Boiler Horsepower.—The term boiler horsepower is defined in several ways; it is not really a measure of the *power* of a boiler but of its evaporative capacity. The standard adopted by the American Society of Mechanical Engineers, and recognized everywhere on the American continent, is:

One **boiler horsepower** is the evaporation of 34.5 pounds of water from and at 212°F.

In order to make use of this definition, it is necessary first to find the equivalent evaporation from and at 212°, and this is found by multiplying the actual evaporation by the factor of evaporation. For example, find the horsepower of a boiler that generates 2860 pounds of dry and saturated steam per hour at 150 pounds gauge pressure when the temperature of the feed water is 65°. Here the absolute pressure is 164.7 pounds per square inch. According to the tables of Marks and Davis, the total

heat at this pressure is $H = 1195.0$ B.t.u. The factor of evaporation is $\frac{1195 - 65 + 32}{970.4} = 1.1975$. The equivalent evaporation from and at 212° is, therefore, $2860 \times 1.1975 = 3425$ pounds of steam per hour from and at 212°. Hence, the horsepower of this boiler is $3425 \div 34.5 = 99.3$ h.p.

The old idea was that a boiler of this capacity would be capable of supplying steam to a steam engine of like horsepower, or 99 h.p. Modern engines are much more efficient, however, and, except under very extraordinary conditions, they require much less steam than this. Still, as a measure of evaporative capacity, this method of computing boiler horsepower is in common use.

STEAM GENERATION

STEAM BOILERS

229. Remark.—From the standpoint of manufacturing costs, steam is one of the most important items of expense in the manufacture of paper. In the making of newsprint, steam and power represent 30% of the conversion cost. Although this ratio is lower for most of the other grades of paper, it is sufficiently important to receive much careful attention. There are two distinct divisions of steam costs in a paper mill; viz., (1) generation, (2) utilization.

230. Fuels.—In a majority of modern paper mills, the boiler plant is treated as a separate department—one that generates steam for use in other parts of the plant. All items of cost involved in operating the steam plant are taken into consideration; the cost per 1000 pounds is calculated from steam-flow meter readings, and is charged to the consuming department at the cost of delivery. Fuel represents from 75% to 90% of the cost of the steam; and since coal is the fuel used by the majority of mills, its quality and adaptability to the boiler-house equipment are of prime importance. Fuel oil is used by a few plants, especially on the Pacific Coast, where market conditions make its use economical. In the East, however, oil is being abandoned, due to fluctuating prices, and because steam, in most cases, can be generated at a lower cost from coal.

Hog fuel (chipped or crushed wood) and wood refuse are used by a few plants on the Pacific Coast and in the Lake states near

lumber-producing centers. A majority of the mills that use pulpwood burn the bark and refuse from their wood-preparing plants.

Natural gas is used by several mills in the southern states, where the supply is still available at a low cost. Steam is also generated from electric power by a number of mills in Canada and northern United States, where there is an excess hydroelectric power supply.

231. Coal.—Various grades of coal are found in a majority of the states and in several of the Canadian provinces. The main producing centers of the coal used in the paper industry are eastern Pennsylvania, where anthracite is mined; southwestern Pennsylvania, West Virginia, Virginia, and Kentucky, where much of the bituminous and semi-bituminous coal is found; and in the Ohio, Illinois, and Indiana section, where many bituminous mines are located. In Canada, much of the coal used in the paper industry is mined in the maritime and western provinces.

A typical average analysis of the different classes of coal is given in the following table, which is taken from "Combustion in the Power Plant," by Marsh:

	Anthracite	Semi-bituminous	Bituminous		Sub-bituminous	Lignite
			Eastern	Western		
Moisture (%)	2.8	4.6	8.6	10.1	22.4	34.4
Volatile matter (%)	1.2	13.5	32.4	32.7	41.2	25.9
Fixed carbon (%)	88.2	76.7	51.3	41.5	32.2	30.9
Ash (%)	7.8	5.2	7.7	15.7	4.2	8.8
B.t.u. per pound	13,300	14,400	12,800	12,000	8,100	7,200
Fusion point of ash	......	2600°F.	2350°F.	2100°F.	2200°F.	......

A few mills are so favorably located that they are able to purchase anthracite screenings at a low figure, but the majority use a fair grade of bituminous coal, either "run of mine" or screenings. Most of this coal comes from the Pennsylvania-Virginia-Kentucky region. A few paper mills use Illinois and other midwestern coals, which have a lower heat value and require a different operation of the boiler house.

232. Coal Characteristics.—In addition to the coal analysis, the burning characteristics of the coal must be considered, as

well as the type of stoker and furnace, and several other details, in order to determine the grade of fuel that is best suited to any particular steam plant. Such characteristics as the coking and the speed of coal ignition are factors of importance. The small amount of sulphur, the nature of the clinkers, the storage adaptability, and similar characteristics, must be determined for any particular grade of coal when considering its selection. A majority of the mills ascertain the coal that is best suited to their conditions by conducting regular tests, and when they find a grade that suits them, they strive to use it at all times. In general, coals having low ash and high B.t.u. value are best suited to the underfeed stokers; while the high-ash coals mined in the Central West, give the best results on a chain-grate stoker. Pulverized fuel burning equipment is not greatly affected by the different grades and qualities of coal, as is the case with stoker-fired boilers, and it is possible to use a cheaper fuel without having any serious trouble. Even the high-sulphur Nova Scotia coals are burned in correctly designed pulverized-fuel furnaces as well as on underfeed stokers.

TYPES OF BOILERS

233. Cross-Drum Water-Tube Type.—Many refinements have been made in boiler construction during the past few years. A majority of modern paper mills have adopted the water-tube type of boiler, shown in Fig. 50. Water-tube boilers present a large heating surface to the radiant heat or hot gases from the fire and thus, also, to the water to be evaporated. The water becomes highly heated and moves rapidly to the steam drum, where there is space for the steam to leave the boiler.

The average size fo the modern boiler unit in paper mills varies between 500 and 1000 h.p., and they are normally operated below 250% of rating.[1] These units are smaller than those of the large central stations, where boilers are rated as high as

[1] The word **rating** here refers to the common practice of allowing 1 h.p. for every 10 square feet of heating surface; that is, under normal operating conditions, 10 square feet of heating surface is considered capable of evaporating 34.5 pounds of water per hour from and at 212°. If, therefore, a boiler evaporated 90 pounds of water per hour for each 10 square feet of heating surface, the boiler would be operating at $90 \div 34.5 = 2.60 = 260\%$ of rating. It will be noted that this method of rating a boiler performance is purely arbitrary.

2000 h.p. and are operated during peak loads at from 300% to 500% of rating.

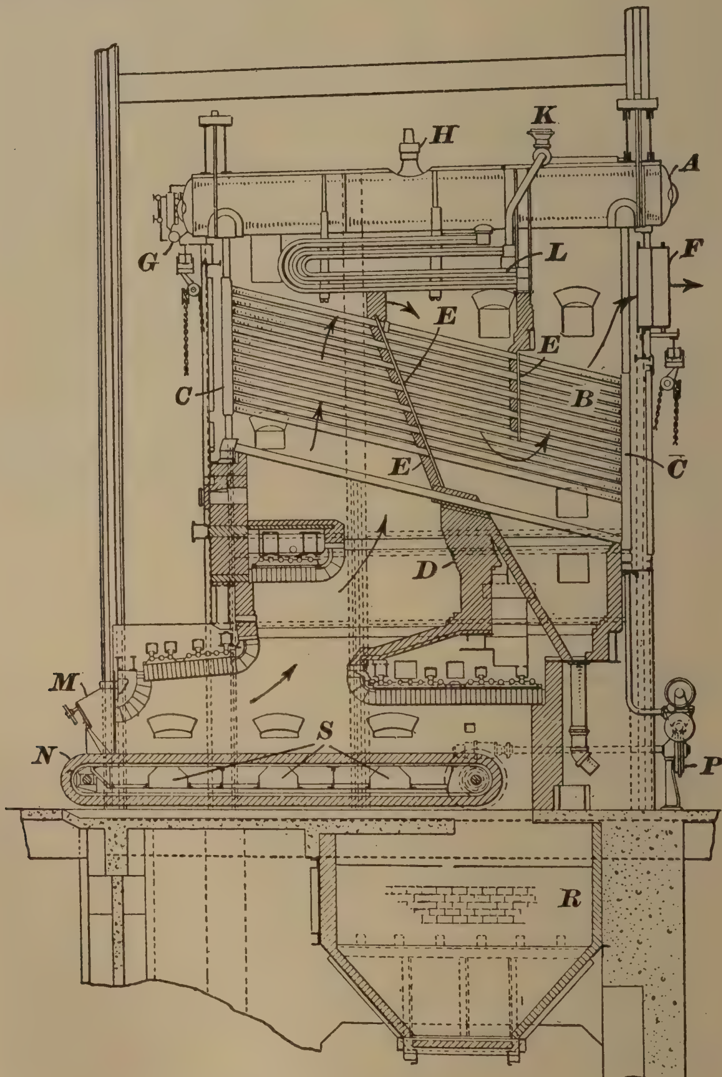

Fig. 50.

A, large drum; *B*, boiler tubes; *C*, headers; *D*, bridge wall; *E*, baffle; *F*, flue-gas outlet; *G*, feed-water inlet; *H*, safety valve; *K*, steam outlet; *L*, superheater connection; *m*, coal hopper; *N*, chain-grate stoker; *P*, stoker drive; *R*, ash pit; *S*, forced draft compartments.

Another type of water-tube boiler, one that in the smaller sizes has been installed in many paper mills, is shown in Fig. 51. This

type has met with great favor because the design and position of the tubes and baffles make it a very rapid steamer.

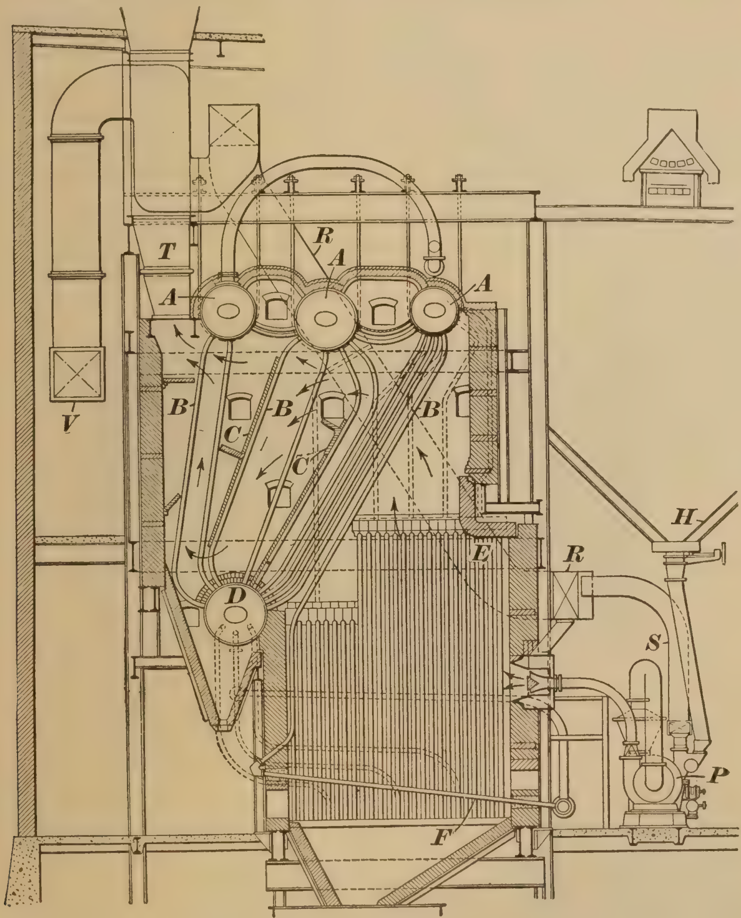

FIG. 51.

A, steam drums; *B*, boiler tubes; *C*, baffles; *D*, mud drum; *E*, watertube side walls: *F*, water screen; (these banks of tubes and water tubes extend the entire width of the boiler); *H*, coal hopper; *P*, unit pulverizer and blower; *R*, preheated-air duct; *S*, primary air to blower; *T*, flue; *V*, fresh-air inlet.

There are a number of other water-tube boilers similar to that shown in Fig. 51 which have vertical or semi-vertical bent tubes in various positions.

234. Return-Tubular Type.—The return-tubular boiler is still used in some plants. This type does not lend itself to modern stoker firing, and it is limited in operation to about normal ratings.

Because of the large volume of water to be heated, the efficiency rapidly falls when forced much above 100% rating. The water-tube boiler rather than the return-tubular, has been generally adopted in modern steam-plant practice, even in small paper mills. The tubes in the return-tubular form of boiler are called *fire tubes.* A combined fire- and water-tube boiler, which is more efficient than one with fire tubes only, is shown in Fig. 52.

The return-tubular part of this boiler consists of a horizontal cylindrical shell, through which numerous tubes extend. The tubes are riveted to the ends of the shell and extend its entire length. Note that there is considerable space above the upper

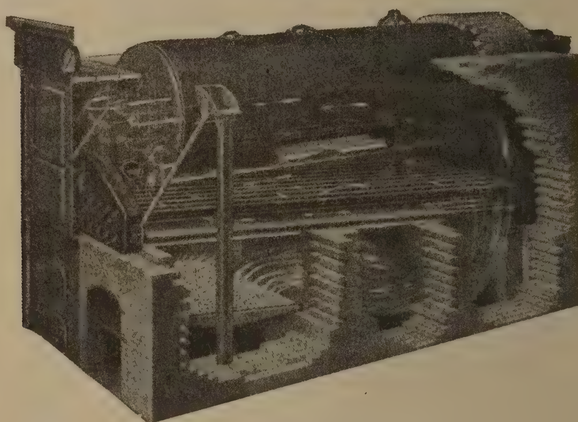

FIG. 52.

row of tubes. The water surrounds the tubes, and the hot gases pass through the tubes, which heats them. The tubes, in turn, transmit their heat to the water. The direction of the hot gases is indicated by the arrows. Note the bank of water tubes under the shell. The gases first pass to the back end, then return, and pass through the tubes, and up the stack.

235. Other Types.—The increased use of pulverized fuel has led to the development of boilers especially designed to burn this kind of fuel. A boiler of this type is illustrated in Fig. 53, which is, in effect, a combined boiler and furnace unit. It embodies a furnace with the evaporating surfaces on all six sides. The four vertical sides and the top are built up of "fin" tubes, and at the bottom of the furnace there is a bank of bare tubes about four rows deep, through which the hot gases pass on their way to the

stack. The principal parts of the installation are designated by name in the cut.

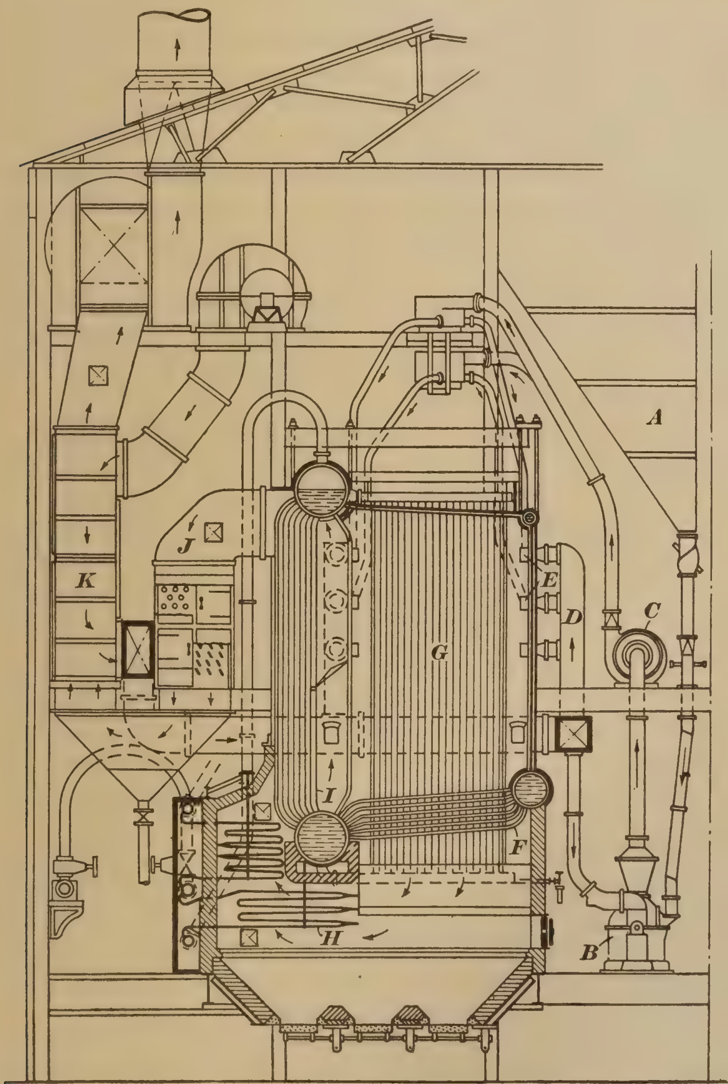

Fig. 53.

Stoker-fired furnaces have been designed with water-cooled walls, "fin" tubes or tubes set in the brickwork, so as to take advantage of the high temperatures in the combustion chamber.

ECONOMIZERS, AIR PREHEATERS, AND SUPERHEATERS

236. Economizers.—Both economizers and air preheaters function as a reducer of flue-gas temperature, thus making operating efficiency higher and the flue-gas losses smaller. The economizer raises the temperature of the water fed to the boiler; and, although usually a separate unit, it is really, in effect, a part of the boiler itself: in some cases, the economizer is an integral part of the boiler. The increased efficiency, due to the temperature rise of the water passing through the economizer, is dependent to a large degree on the temperature of the outgoing gases and the area of the economizer surface. In general, a well-designed economizer should give 3% to 5% higher operating efficiency to the plant, and it should reduce the temperature of the exit gases to 250° or 300°F. The location of an economizer in a boiler installation is shown in Fig. 53.

237. Air Preheaters.—Air preheaters are simply additional heating surfaces, so located that the gases leaving the boiler or economizer must pass through them. The temperature of the fresh air drawn through the preheater is raised by the difference between the temperature of the fresh air entering the preheater and the temperature of the incoming flue gases. For example, if the temperature of flue gases is 550° and of the fresh air 70°F., the air may be theoretically heated to 440°, a result that is nearly obtained in practice. The preheated air is then fed to the furnace, and there used in place of fresh air. Thus, there is not so great a difference between the air and the furnace temperature, and the heat required to raise the temperature of the air from, say, 70° to the temperature of the preheated air is saved.

There are three general types of preheaters; viz., plates, tubes, and rotary, the rotary and plate types being most commonly used. The phantom drawing, Fig. 54, shows a perheater of the rotary type. The course of the air and gases is clearly indicated, a small fan being used to draw the air into the preheater. In the plate type, there are two nests (or sections) of plates, one of which is heated by the flue gases, while the other is heating the inlet air. A damper automatically reverses the flow at short intervals. In the rotary type, Fig. 54, a rotating disk, or grid, continually brings heated metal from the hot gas duct to the fresh-air inlet duct.

Various tests of air preheaters have indicated an increase of 4% to 6% in the over-all efficiency at ratings between 125% and 200%.

While the economizer may be preferred under some conditions, the preheater is better adapted to other installations, and it is probable that a combination of the two will give the best results. In many case, the preheater has received considerable preference in paper mills, especially where pulverized fuel is used. The investment cost is less than an economizer installation, and the entering feed water is frequently at a temperature so low as to cause trouble by sweating, as well as corrosion of tubes, unless the water be de-aerated. On the other hand, highly preheated air may give trouble in some steam installations.

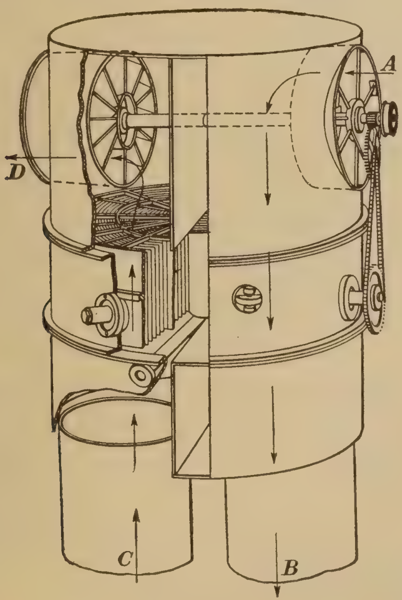

FIG. 54.

238. Superheaters.—A **superheater** is a device or appliance for heating steam that is not in contact with the water from which it was formed. Superheated steam contains more heat units per pound than the saturated steam from which it was formed, and the temperature can be raised much higher than saturated steam of the same pressure. As may be supposed, in order to superheat the steam, it must be removed from the boiler to a separate container, called the *superheater*, where more heat is applied to it. The tubular superheater is usually placed between the boiler tubes; it consists of a number of bent tubes, with their ends expanded into headers, and is located in the upper part of the

combustion chamber of the boiler. The radiant superheater is located in the rear or side walls of the furnace. A tubular superheater is shown at *L*, Fig. 50.

BOILER FURNACES AND SETTINGS

239. Size of Furnace.—High boiler ratings and the use of pulverized coal necessitate greater furnace volume for more rapid combustion and higher efficiency. There is an economical limit to the size of the furnace, and the practice in the central-station field indicates that the best conditions are maintained when the furnace space is sufficiently large to liberate 20,000 to 30,000 B.t.u. per hour per cubic foot of furnace volume. This is equivalent to between 4 and 5 cubic feet of furnace volume per rated horsepower of the boiler, depending on the percentage of rating operated. Efforts are being made to reduce the size of the furnace, but 4 cubic feet per rated horsepower appears to be a reasonable figure for present furnace design. A majority of the existing furnaces have only 25% to 50% of this space; consequently, incomplete combustion, and an increase in the upkeep and repair cost, is the result of inadequate furnace volume.

240. Furnace Walls and Arches.—Standard firebrick construction is satisfactory when the boilers are operated at not over 175% of their normal rating; but, since modern practice has speeded up steam generation to 300% or more during peak loads, the higher furnace temperatures then required are destructive to the front, side, and back walls. In order to offset the excessive repair costs resulting from high rates of combustion, and to reduce loss of heat by radiation from furnace walls, the three following general types of furnace walls and arches have been developed: (*a*) hollow air-cooled; (*b*) water elements in walls; (*c*) water-tube walls.

In the air-cooled type of furnace, the danger of wall destruction is greatly minimized. The walls are usually so constructed that one section may be replaced without disturbing the rest of the setting. The air thus preheated is used under the stoker or in a pulverized fuel burner. Where air-cooled walls are in use, air preheaters are unnecessary, since the temperature of the air for combustion is raised sufficiently high by its passage through the hollow walls.

Water elements in the side or back walls usually consist of tubes in the settings, or water tubes protected by special carborundum blocks. Since the highest temperatures occur 3 or 4 feet above the stoker, these water elements are placed in the wall near the junction of the stoker and furnace wall. Because of the reduction in temperatures, this type of equipment eliminates serious clinker formation, and it helps to increase the efficiency of the furnace by absorption of radiated heat.

The water-tube wall, which is being widely adopted by central stations and modern paper mills, is similar in its results to the water elements, just described. The heat-absorbing surfaces, which are inside of the furnace, should not come into direct contact with the flame, but with the highly heated products of combustion and incombustible inert gases at some point beyond the flame. The fin-tube water walls and similar water tubes set in carborundum blocks are virtually a part of the boiler, and the rated horsepower is increased almost in proportion to the area of the water-tube wall exposed. Recent tests indicate that, while the efficiency of the entire unit is slightly increased by the use of fin-tube side walls, greater economies are achieved through the reduction of maintenance costs.

241. Furnace Design.—The choice between economizers and air preheaters, as well as the question of water- or air-cooled walls, for the modern paper-mill boiler plant may be considered a distinct problem at each mill, though several common fundamental principles are involved.

Where a chemical pulp plant is operated in conjunction with the paper mill, there is a smaller amount of condensate being returned to the boiler than in a mill that produces paper only. If the cold raw-water make-up exceeds 30%, increased temperatures of the feed water are desirable for good operating conditions; therefore, economizers and water walls should be considered in the plant design. On the other hand, if the condensate all comes back to the boiler house at high temperatures, the most effective method of heat recovery is by air preheater or air-cooled walls. The problem is largely a question of temperature difference between the flue gases and the medium that reclaims the heat in those gases, whether it be water or air.

In the average mill, a combination of the economizer and air preheater, together with the water walls in the furnace, meet

all the conditions. If economizers with large heating surfaces are used, air-cooled walls are advisable, since the temperature of the outgoing gases from the economizer would be so low that it would not be feasible to attempt a further reclamation of heat.

242. Mechanical Stokers.—Except in some small mills, the boiler furnace is not fired by hand, the coal being mechanically fed by either stokers or blowers.

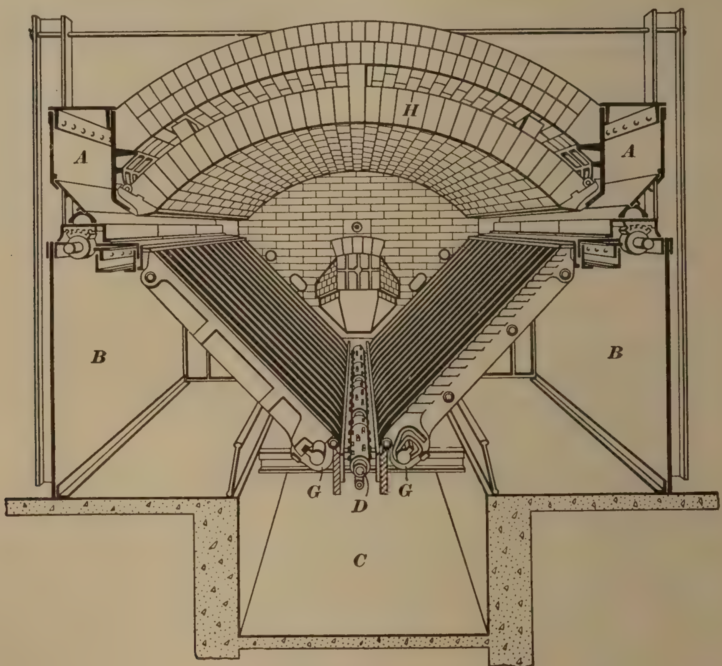

FIG. 55.
A, coal supply; *B*, air supply; *C*, ash pit; *D*, clinker grinder; *G*, grates; *H*, arch.

There are four general types of mechanical stokers in common use: (1) the front-inclined; (2) the side-inclined; (3) the chain-grate; and (4) the underfeed stokers. The latter is further subdivided into: (*a*) multiple-retort; and (*b*) single-retort. These various classes originate from the methods of coal feed.

As the name implies, in the **front-inclined** (overfeed) stoker the coal is fed in front, on top of the stoker. An eccentric shaft and arm is attached to a reciprocating plate that feeds coal from the hopper. Air is blown in through the boxes below the grates, and the force of the draft can be regulated. As the coal

farther down on the stoker burns, the movement of the mass is away from the front, thus allowing a new supply of coal to come onto the stoker. While this is occurring, the moisture in the fuel evaporates, the volatile matter comes off and burns, and the carbon in the resulting coke is consumed. The ash is discharged through the clinker crusher at the rear, or by dumping the grates.

In the **side-inclined stoker,** Fig. 55, the coal comes to the stoker from both sides, and the ashes are dumped at the middle or low point of the stoker.

The **chain-grate stoker** is shown in Fig. 50. Here the moving chains (continuous) take the coal from the hopper, and the coal lies at the same depth across the full width of the stoker. The ash drops off at the rear, as the chains that form the stoker go

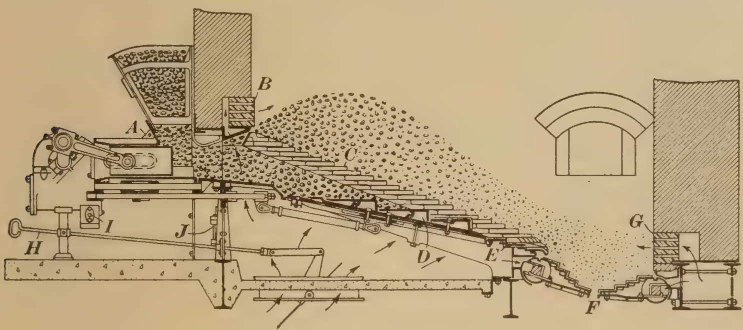

FIG. 56.

around the sprocket at the rear end of the stoker. The depth of the coal on the stoker can be controlled by the gate opening in the hopper, and the rate of feed is regulated by the speed of the chains. This type of stoker, which is used in the Middle West on low-grade coals, has been much improved by application of the compartment forced draft, thus making possible different pressures under the several combustion areas of the stoker.

243. Very wide use is accorded to the **multiple-retort underfeed stoker,** Fig. 56, especially where eastern coals are fired. The number of retorts and the length of the stoker have been materially increased for the large boilers; and the application of varying forced draft under different parts of the stoker, as well as the use of the clinker crusher, are examples of recent improvements in the design. Note water section in rear wall. The fuel

in the multiple-retort stoker here shown is fed to the stoker by the ram under the hopper; the fuel moves from front to back by the action of the distributing rams, which vary in size and in length of stroke.

In the **single-retort underfeed stoker,** Fig. 57, the coal overflows over the central channel and moves down a sloping grate, largely by gravity, from the center to the side of the furnace.

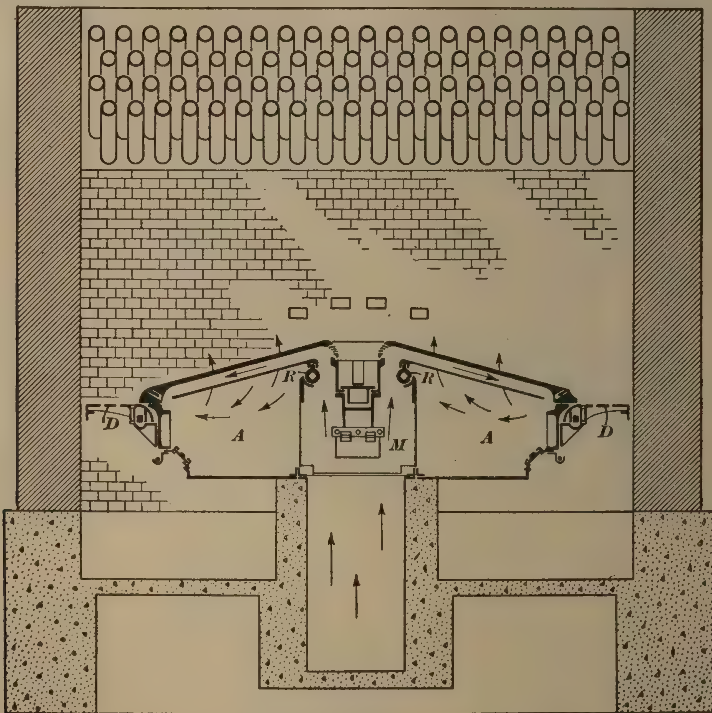

Fig. 57.
M, main air chamber; *A*, auxiliary air chamber; *R*, rocker bar; *D*, dump trays.

As the boiler is forced to high ratings, the hot zone of combustion is near the side walls, and the deterioration of the brickwork is much more rapid than in the multiple-retort stoker.

The underfeed stokers have been adopted by many of the modern paper mills because they render it possible to carry peak loads up to 300%. The design of these stokers is simple, and they are well adapted to most furnaces, since it is not necessary to have special arches, bridge walls, or other special equipment.

244. Selecting a Stoker.—Some of the items to be considered when selecting a stoker are: (*a*) the kind of coal (fuel) available; (*b*) the draft conditions; (*c*) the method of fuel feed, as well as the thickness of the fuel bed when coal is fired; (*d*) the system of ash and clinker removal. Other points of importance are: the ability of the stoker to handle fluctuating loads; the maintenance and replacement costs, together with the power and labor required for operation. The net efficiency of the boiler is of major importance, and all other factors should be weighed while keeping this feature in view.

BURNING PULVERIZED FUEL AND WOOD REFUSE

245. Pulverizers.—The pulverizing equipment now on the market may be placed in three general classes: (*a*) impact, or hammer, mills; (*b*) centrifugal mills; (*c*) ball mills. The impact and centrifugal mills depend on high-speed operation to pulverize the coal.

The **impact** and **swing-hammer mills** are similar in action, since pulverization is accomplished by the impact of moving arms or hammers against the coal. The hammers or paddles of the impact pulverizer are subject to excessive wear, and must be changed every 10 to 20 days, depending on the amount of coal handled. As the hammers wear, the coal particles become coarser, and the burning conditions are altered.

In the **centrifugal mill,** which also depends on high speed, the grinding action is caused by balls or rollers, held in a race inside of the casing. Centrifugal force and the rolling and grinding action of the balls against the casing, cause pulverization of the coal. The fineness of the coal particles produced by the impact and centrifugal mills is approximately as follows: passing through a 200-mesh screen, 70%; through a 100-mesh screen, 88%; through a 50-mesh screen, 98%.

The **ball mill** consists of a slowly-revolving steel shell, filled with balls, which grind by the impact of the balls against the coal. It requires more floor space than the other types of pulverizers. The degree of pulverization obtained with this mill under normal operating conditions is greater than with other types of pulverizers, since over 96% of the coal will pass through a 200-mesh screen. The maintenance cost of a ball mill is much less with the other types, but it is not so flexible in operation.

246. Moisture Limits.—Several types of pulverizing mills use air as a medium for removing powdered fuel from the machine. This helps to dry the coal and to convey it to the boiler or to storage. Many of them use preheated air, and the temperatures are often as high as 250° to 400°F.

In any system of preparing coal, the moisture it contains is an important factor, since as the moisture increases, the power consumption goes up and the capacity of the mill is decreased. While it is desirable to use coal having 10% moisture or less, it is possible to pulverize it up to 12% to 15% moisture without drying the coal.

247. Pulverized-Fuel Systems.—There are two general types of pulverized-fuel systems used in industrial work: (*a*) the unit system; (*b*) the bin-and-feeder, or central, system. The **unit system** consists of one pulverizing unit, which is placed near the boiler, and the coal is fed directly into the furnace as it is pulverized. Some larger boilers have two unit pulverizers, operating either singly or in parallel. The unit system is in successful operation on large and small boilers throughout the combustion field and is especially suited to the average paper-mill steam plant.

The **bin-and-feeder, or central, system** includes crusher, dryer, pulverizing mill, storage bin for the pulverized coal, and the necessary conveying system to storage, and from storage to boiler. Usually, sufficient coal is pulverized in 8 or 10 hours to operate the boiler for a period of 24 hours or more. This system is especially adapted to very large operations, where it is desired to keep the pulverizing machinery in a separate building, and where large boilers are used.

248. Comparison of Stokers and Pulverized Coal.—The combustion of coal in pulverized form appears to be a logical process: the operation is less affected by different grades of coal used than when stokers are employed. The powdered-coal furnace is more flexible and takes up the load fluctuations in the steam plant better than does the ordinary stoker.

The modern pulverized-coal-burning boiler (see Figs. 51 and 53) operates at high efficiency; this is also true of the latest type of underfeed stoker, and most modern installations appear able to get equally good results by either system. Stokers do not require so much furnace volume as pulverized-coal systems,

and many makes of stokers are better adapted to small boilers under 500 h.p. The stoker has a distinct advantage over the unit pulverizer when wet coal is used, since stoker operation is not so seriously affected by moisture as a pulverized-coal system.

249. Burning Wood Refuse.—The Dutch oven is widely used to burn wood refuse; but, as usually operated, it cannot be considered an efficient apparatus. More satisfactory results are had by burning *hog fuel* (chipped or crushed wood) and bark in combination with coal on an underfeed stoker, when the moisture in the refuse does not exceed 60%. On the Pacific Coast, the step-grate stoker and furnace, see Fig. 58, has been

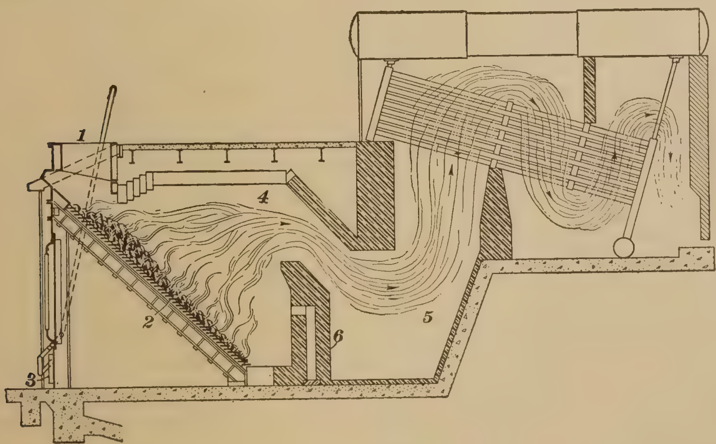

Fig. 58.

1, feed; 2, step grate; 3, draft damper; 4, primary combustion chamber; 5, secondary combustion chamber; 6, bridge wall.

generally adopted. Relatively high operating efficiency is obtained with this equipment, since its design makes possible even distribution of fuel by the overfeed method. Preheated air is introduced between the primary and secondary combustion chamber, thus creating favorable conditions for burning this type of fuel. When bark is burned, it may be quite wet before being charged; some of the moisture may be removed by pressing, as described in *Preparation of Wood*, Vol. III, Sec. 2.

WASTE-HEAT BOILERS AND STEAM ACCUMULATORS

250. Waste-Heat Boilers.—Considerable heat is produced in the recovery system, in both sulphate and soda mills, and it is

the practice in modern plants to install **waste-heat boilers** behind the incinerators, in order to recover as much as the heat in the incinerator gases as possible. Sufficient steam is produced in a well-designed plant to supply 30% to 50% of the steam requirements in a sulphate mill. Such equipment makes it possible for a mill materially to reduce the cost of producing kraft pulp.

Recent experiments made in evaporating waste sulphite liquor indicate that it is feasible to concentrate the solids in this liquor to about 50% to 60%, and use them as fuel. Authentic estimates show that it is possible, by means of a correctly designed evaporating and combustion plant, to produce sufficient steam to do all the evaporation and still have some left over for other process work. Furthermore, this plant will solve the steam-pollution problem, caused by disposal of sulphite liquor.

251. Steam and Power Balance.—One of the important features in the design of a paper mill is to install power-generating equipment that will correctly balance the steam requirements in the various departments, so that the losses due to wastage in exhaust steam, hot water, etc., are reduced to a minimum. The adoption of the extraction turbine has successfully met this condition in a number of modern installations. Where steam is required in the chemical-pulp plant at 100- to 125-pounds pressure, and in the paper mill at 15- to 20-pounds pressure, it is possible to create a proper *steam balance* by the installation of a two-stage extraction turbine equipped with a condenser. This equipment maintains the electric power balance at the same time, and the power thus produced is very low in cost, especially where high initial pressures, up to 400 pounds, and approximately 200° of superheat, are used. Such a system meets the demands on both the chemical-pulp plant and the paper machines, where the prime movers of the latter are tied in with the same general low-pressure system. It is possible to utilize all exhaust steam from the paper-machine prime movers, even when one paper-making unit is not consuming all of its exhaust steam in process work.

252. Steam Accumulator.—The steam accumulator has been adopted by a number of mills: it assists in maintaining a steam balance. The **steam accumulator** is a huge reservoir of steam, placed in hot water, which acts (as does a flywheel) to take

care of the peak demands of the chemical-pulp mill or paper machines, by automatically storing the excess steam whenever it is available. The particular features of this system are the valves and steam distribution devices that assist in the absorption of excess steam by the water when the pressure rises above that required, and its discharge when the pressure falls, thus maintaining practically constant pressure without sudden forcing of the boiler. It is advisable where steam is generated by electric boilers. It also has a good field of application in chemical-pulp plants, to smooth out peak steam demands and to permit more efficient boiler-plant operation.

BOILER-HOUSE AUXILIARIES

253. Pumps.—The most essential item of accessory boiler equipment is the pump that forces the feed water into the boiler. This pump must operate against the steam pressure, operate intermittently, and work under hard conditions.

The three principal types of pumps used for pumping feed water are: (*a*) direct-acting steam pumps; (*b*) centrifugal pumps (both single and multistage); (*c*) power-driven displacement pumps. All these types are described in Part I of this Section.

The **direct-acting steam pump** is one of the oldest types; it is simple in construction, and the maintenance cost is relatively low. Where exhaust steam is desired to raise the temperature of the feedwater going to the boilers, such a pump is very practical, and it has been used in the past by many paper-mill boiler houses operating at pressures under 150 pounds, gauge, and supplying feed water to a battery of boilers under 500 h.p. each.

The **centrifugal pump,** especially the multistage type, is more efficient in operation than any other type; it is usually selected for the more modern boiler houses. Sometimes, this is steam driven, but more often the installation for boiler feeding is so equipped that one set of pumps can be operated by electric motors and the other set by steam turbines. This enables the plant to maintain more uniform feed-water temperature conditions, both winter and summer, since the exhaust steam is used to heat the feed water in cold weather.

The **power-driven plunger,** or **displacement pump** is not used to any extent for boiler feeding. The duplex and triplex types are satisfactory on lower pressures, and where the temperature of

the feedwater is not too high. Because of maintenance cost and low efficiency, however, this type of pump is not particularly satisfactory for boiler feeding.

254. Feed-Water Heaters.—Feed-water heaters are classified under two general types: (*a*) the closed type; (*b*) the open type.

The **closed-type feed-water heaters** all work under pressure (usually, boiler pressures), and there are two general kinds—the

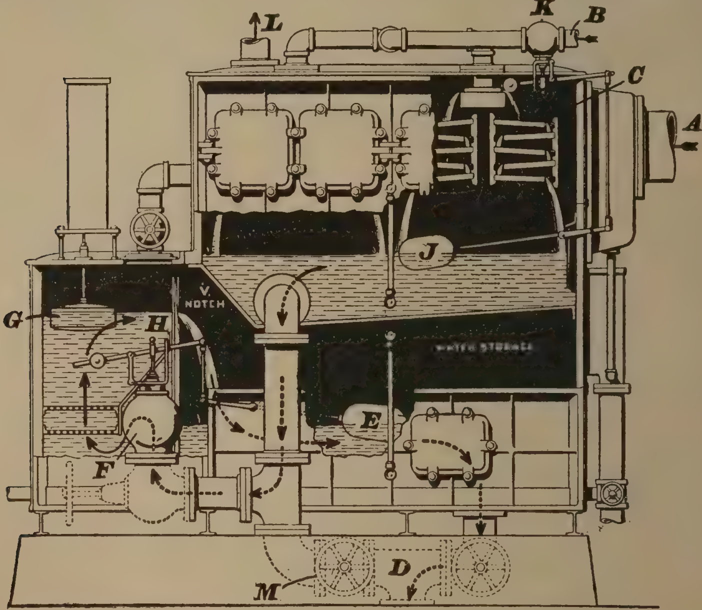

Fig. 59.

A, steam inlet; *B*, water inlet; *C*, baffle plates, where steam is absorbed; *D*, water outlet; *E*, steam control valve; *F*, water float valve; *G*, water-level regulator; *H*, V-notch, water-measuring weir, *J*, float in condensate reservoir, operating valve *K*; *K*, water-inlet control valve; *L*, atmospheric relief; *M*, direct water-outlet valve.

water tube and the steam tube. In the *water-tube type*, the feed water goes through tubes, and the steam is in the body of the heater; but in the *steam-tube type*, the reverse of this occurs, the steam going through the tubes. These closed heaters may be so designed that the water may flow through the heater only once; or the tubes may be so arranged that the water passes through several times.

The **open-type feed-water heater** is preferable in paper-mill work, though it takes up considerably more space than the closed type. Figure 59 illustrates the standard make of an open

feed-water heater, showing the heating elements above and a V-notch metering section below. Such a heater usually works under no pressure, or with exhaust-steam pressure, up to 10 or 15 pounds. The temperature of the feed water in the case of the open heater is raised by the direct contact of the exhaust steam, which goes into the water. It is therefore necessary to have oil separators on the steam line, and the *hot well* (reservoir for condensed steam) must be employed, since this is, to some extent, a settling basin and a reservoir for the feed pump.

The water economizer is usually classified as a feed-water heater, though this is more often considered an actual part of the boiler. Although the economizer heats the feed water, it is under the same pressure conditions as the boiler itself, and in many cases, is a unit section of the boiler (see Fig. 53).

255. Mechanical Draft.—Mechanical draft is a feature of practically all the modern boiler installations in the paper industry; it is a method of obtaining economy of operation, or of increasing the capacity, or both. Both *forced-* and *induced-draft* fans are used, according to the design of the boiler, stoker, stack, and other factors. A representative boiler installation having underfeed stokers, uses forced-draft fans to supply air under the stokers, and an induced-draft fan to draw the hot gases through the economizer or air preheater, and deliver them to the stack. Such an installation makes possible a close regulation of the draft and a better operation of the boiler, since it eliminates the difficulty of different draft conditions caused by varying atmospheric conditions, which may affect a natural-draft system. Both the forced- and induced-draft fans are usually driven by motors, and the volume of air may be adjusted by using variable-speed motors, or by dampers when alternating-current motors are used. The variable-speed steam engine or turbine is also employed, and is especially adapted to the forced-draft fan whenever the exhaust steam can be used in the feed-water heater. If the feed-water is already at a temperature of about 200°F., an electric drive might be preferable.

The forced-draft fan must overcome the resistance offered by the fuel bed; and in the best boiler installations, it must be able to deliver pressures up to 8 inches of water where the boilers are operated at high ratings.

There are three general types of forced-draft fans: they have backwardly curved, radial, or forwardly curved styles of blading.

256. Soot Blowers.—Soot blowers are an important adjunct to a boiler house; they are used both on boiler tubes and on economizers. **Soot** is ash and particles of unburned carbon, and it is a very effective heat insulator. Consequently, soot must be removed periodically—usually every 48 hours—in order to keep the outside of the boiler-tube surfaces clean. The soot blowers are so arranged in the boiler that when the proper valve is open, a jet of steam at boiler pressure is directed in between the tubes, and the accumulation of soot is blown off. The blowers are located at different points along the boiler setting, on both sides, and are so constructed that they can swing through arcs of nearly 180°, thus enabling each blower to clean a large area of boiler-tube surface.

257. Regulators and Gauges.—The automatic **feed-water regulator** is one of the most important pieces of regulating equipment in the boiler house, and has displaced hand regulation to a large degree. The *continuous type* gives satisfactory results, since the feed water is being forced into the boiler at all times. The *intermittent type* is so designed that the throttle or valve opens whenever the water line drops below a certain point in the boiler. Several kinds of feed-water regulators have an arrangement that retards the feed immediately after a period of peak steam demand, which would normally require a large amount of make-up water to bring the level in the boiler to the correct height. This arrangement is of considerable assistance in efficient boiler operation, since it prevents too rapid an influx of feed water to the boiler, and overcomes the resulting lowering of capacity when the steam demand is high for a brief period.

258. Draft Control.—The automatic **draft control** has been well developed, and it is of marked assistance in good boiler operation. Some of these automatic controls depend on the boiler pressure, a few on the air pressure over the fire, and some on both. They regulate the speed of the stoker, as well as the volume of air required to maintain proper combustion, by changing the speed of the fans or altering the damper opening. In pulverized-fuel plants, this control can regulate the amount of coal going to the furnace and the air required by it, just as in the case of stokers. Since the difference in draft is due to a difference in pressure caused by a variation in gas density, the individual *draft gauge* in different parts of the boiler is the usual installation.

This shows the conditions at each pass, and it helps in maintaining proper combustion conditions.

259. Gauges.—All boilers are equipped with standard pressure gauges, and many plants have adopted the large-dial *master gauge*, which is located in a conspicuous position in the boiler room so that all the firemen can see it. In addition to this, the continuous recording pressure gauge is also used, so that any changes in conditions can be traced back. Recording temperature gauges (thermometers) on the feed water and steam are also necessary parts of the equipment in a well-operated boiler house; likewise temperature recorders for flue (exit) gases.

METERING AND MEASURING APPLIANCES

260. Reasons for This Equipment.—In order to calculate the cost and efficiency of operating a boiler, it is essential to know: (1) the weight and quality of coal used; (2) the volume of steam generated. Such other information as temperatures of feed water and flue gases, pressures, superheat, etc., are also necessary.

261. Coal Scales.—There are several methods of ascertaining the weight of coal used in boilers. One is to weigh the cars of coal on the track scales and unload the cars into the hopper in the boiler house. Another widely used device is the traveling weigh larry, which delivers coal to each boiler. The *continuous weightometer* is used where coal is conveyed to the hopper of the boiler house on a continuous belt conveyor. The intermittent, automatic, hopper-type scale is sometimes used for crushed coal and other granular materials.

It is possible to get reasonably accurate results by measuring the volume of coal, and a metering device of the revolving worm-gear type can be used in the chute coming from the hopper to the stoker, provided the coal comes through in a uniform manner. Another method of determining the volume of coal is by a series of counters on the stoker rams. The rams can also be calibrated in weight of coal. For accuracy, the weight figures should be supplemented by regular average determinations of the moisture in the coal.

262. Water Meters.—It is customary to install a water meter in the feed-water line to the boilers, and there are two general types: (1) the venturi meter; (2) the orifice. The **venturi meter**

is considered the more accurate method for measuring the amount of feed-water used, although the **orifice,** when properly installed, gives satisfactory results.

263. Flow Meters.—The action of steam-flow meters is based on the difference of pressure before and after the fluid enters a restricted area in the main, which may be in the form of an orifice, a venturi[1] meter, or a Pitot tube. Since steam is a vapor, it is more difficult to measure than a liquid; but where the orifice or throat (meter) is properly installed and the steam-flow meter is properly designed, it should be possible to measure the steam flow through a pipe, with an error of not more than about 2% plus or minus. This applies to conditions where the steam flow is over 30% or 40% of normal, since no flow meter now in use can accurately measure the steam if the volume falls much below 25% of the amount normally expected to go through the steam main.

There are two general types of steam-flow meters, one having a mechanical and the other an electrical recording device. It is possible to locate the recording mechanism of the electric steam-flow meter at any desired point; but in the case of the mechanical recording instrument, it must be located near the orifice or meter body.

One type of meter that has been largely adopted in central stations and paper-mill boiler houses is the *boiler meter*. This consists of the ordinary flow meter that records the volume of steam generated in a particular boiler, together with the amount of air being used. The pens on the recording chart that show the air flow and steam flow are so adjusted that the lines coincide whenever correct combustion conditions are present in the furnace. The air pen is usually set for a predetermined CO_2 and is checked by Orsat[2] tests. Generally, the temperature of the flue gases is recorded on the same chart, in order to indicate changes in the heat losses leaving the boiler; the information thus provided enables the firemen to operate the boiler more efficiently, by keeping the air- and steam-flow lines together.

264. Carbon-Dioxide Recorders.—The volume of oxygen required to burn the carbon in coal to carbon dioxide CO_2 is theoretically equal to the carbon dioxide formed, since O_2 in the

[1] See *Mechanics and Hydraulics*, Sec. 1, Vol. II.

[2] A chemical apparatus for accurate determination of the constituents of flue gas; it is described in the Section on *Sulphite Pulp*, Vol. III.

air supply is replaced by an equal volume of CO_2. Oxygen is very nearly 21% of air by volume, and the amount of CO_2 in the flue gas is a measure of the efficiency of combustion. An excess of air involves a waste of heat, as does incomplete combustion, with carbon monoxide CO in the flue gas. At least one make of CO_2 recorder measures also the CO.

Three principles characterize the various makes of CO_2 recorders, which may be designated as: (1) chemical; (2) mechanical; (3) electrical. The **chemical CO_2 recorder** is based on the principle of absorption of carbon dioxide in the stack gases by a chemical; a sample is taken intermittently, and the test is automatically made and recorded on the chart. The **mechanical CO_2 recorder** depends on the difference in weight between air and carbon dioxide, which is indicated by the difference in the speed of revolving elements in air and gas. The **electrical CO_2 recorder** is based on the conductivity of CO_2 gas as compared with that of ordinary air. The chemical CO_2 recorder is the oldest form and is most widely used; but since it is necessary to change the chemical at the proper time, difficulty is often experienced in keeping it operating properly under average boiler-house conditions. Both the mechanical and the electrical CO_2 recorders are delicate instruments. The proper sample of the gas to be tested must be used in all three, which must represent average stack conditions and be free from dirt and foreign matter. It is necessary to check all CO_2 recorders against an Orsat apparatus, to make certain that they are working properly.

265. Temperature Recorders.—It is customary to have temperature recording devices for the flue gases in the form of a pyrometer, and this is usually placed in the last pass of the boiler, just as the gases go into the stack. With air flow and temperature recorded, the loss of heat in flue gases can be found. Such equipment as recording thermometers on the feed water going to and leaving the economizers, are usually a feature of well-equipped boilers.

BOILER OPERATION

266. Combustion.—A few basic principles of the theory of combustion will now be touched on. **Combustion** is the *rapid* chemical union of oxygen with carbon, hydrogen, sulphur, and

some other elements; the reaction that takes place results in heat and light. When this combination occurs in exact proportions, perfect combustion is attained; but this last is not possible in the ordinary boiler and furnace installation, since more than the theoretical amount of air is required to meet operating conditions. This *excess air* is, under normal conditions, about 50% more than the theoretical requirements; it is a direct source of waste, since it results in an increase in the products of combustion,—the flue gases,—which carry off a large amount of heat. The heat lost in this way may be calculated by the formula

$$h = ws(t_1 - t_2)$$

in which h = heat loss in B.t.u. per pound of fuel burned; w = weight of gases in pounds per pound of fuel; s = the specific heat of the gas mixture (oxygen, nitrogen, carbon dioxide, etc.); t_1 = temperature of gases entering stack; and t_2 = temperature of air entering the furnace, both in degrees Fahrenheit.

Coincident with the application of the principles of combustion are such factors as: (*a*) the thickness and condition of the fuel bed; (*b*) the point of introduction of the air to the furnace; (*c*) the temperature of the air admitted to the furnace; (*d*) the circulation and movement of air in order to eliminate air pockets and cause stratification of gases.

The following little table shows the value of the specific heat (average) of certain gases and water vapor, for several temperatures in degrees Fahrenheit:

Gases	200°	400°	600°	800°
CO_2	0.206	0.214	0.222	0.228
O	0.217	0.219	0.221	0.222
N and CO_2	0.245	0.247	0.249	0.251
H_2O (vapor)	0.454	0.458	0.464	0.470

In calculating the heat loss in flue gases, it is customary to take the average specific heat as 0.24, and this may be substituted for s in the above formula.

267. Feed-Water Treatment.—The feed-water problem is closely allied to boiler operation, particularly where a large percentage of raw make-up water is required. In pulp and paper mills where a large percentage of the steam is used in the cooking of chemical pulp, the matter of feed water is even more important.

Water and its treatment is adequately discussed in Part 4 of this Section.

268. Points to be Considered in Boiler Operation.—In actual practice, the following are some of the points to be considered in boiler operation: (1) the regulation of the fuel bed, to see that it is of the right thickness and has no air holes in it; (2) the correct regulation of air and draft (both forced and induced); (3) keeping the furnace free from slag and clinkers; (4) the removal of soot from the tubes, to keep them clean; (5) the selection of the proper type of furnaces, settings, and baffles (this is highly essential); (6) the elimination of leaks in valves and steam lines; (7) provision for insulation sufficient to retard radiation.

269. Losses in Boiler Operation.—In general, losses in boiler operation are divided into two groups: those due to the construction and design of the boiler itself; and, most important, those due to operation. According to Marks, these losses may be tabulated as follows:

Losses in Boiler Operation

A. Losses not primarily due to operation	Per cent of total heat of fuel	Per cent of total loss
(1) Loss due to moisture in coal	0.35	1.1
(2) Loss due to moisture formed in burning the coal	3.26	10.4
(3) Loss due to moisture in air (negligible)		
(4) Loss due to radiation, and unaccounted	4.91	15.6
Total	8.52	27.1
B. Losses greatly affected by operation		
(5) Loss due to heat carried by flue gases	16.37	52.0
(6) Loss due to undeveloped heat of unburned carbon monoxide CO	1.78	5.8
(7) Loss due to unconsumed carbon in ash	4.75	15.1
Total	22.90	72.9

This tabulation indicates that approximately 70% of the losses are jointly chargeable to the operating engineers, firemen, and management, while the remaining losses are caused by the fuel and inadequate equipment.

270. Operating Efficiencies.—Since the human element is such an important factor in boiler-house operation, the value of complete and adequate reports is evident. These reports should be in such form that the operating engineers and firemen shall be able to analyze them, and they should be currently before the operators. A form that is widely used in the paper industry for the steam-plant efficiency report, is based on the 1923 A.S.M.E. Test Code for stationary steam boilers; attached to this report, and a part of it, are definitions and directions to show how the report is to be filled in. Both the form and the methods of calculation represent standard practice.

The *over-all efficiency* is largely used by boiler-house operators and engineers to determine what results are being obtained. This can be easily calculated, and it gives the operator a quick analysis of the situation; it may be calculated every day, or every 8-hour shift per boiler, if desired. The cost of generating steam, however, is the main item to be found, and as the efficiency is increased the cost of generating steam should decrease.

271. Cost of Steam Per 1000 Pounds.—Closely allied to the steam-plant efficiency report, and even more important, is the cost of generating and delivering 1000 pounds of steam from and at 212°F. As the efficiency of a particular plant is raised, the cost should be lowered almost in direct proportion; consequently, the two reports are correlated, and both are required in the analysis of steam-plant operation. Below is given a standard form of cost report, which is used by a large number of mills in North America. The item of "Superintendents" includes all superintendents or non-operating foremen; "Firemen" includes all men engaged in firing and cleaning boilers; "General" includes all other labor in the boiler house. The repair labor and materials are kept separate, as is the labor involved in rehandling fuel from the storage pile to the boiler house. The fuel—whether coal, hog fuel, wood refuse, or oil—is charged by weight. Such items as depreciation, taxes, and insurance on the steam plant are necessary, as they aid in getting the true cost of producing steam. The figures for the items filled in are assumed, but they are representative of costs in the paper industry.

Cost of Steam
(Cents per 1000 pounds from and at 212°F.)

Labor—Superintendents	0.40
Firemen	3.61
General	0.44
Total labor	4.45
Fuel-handling expense	0.30
Power—Electric	0.86
Lubricants	0.06
Supplies	0.20
Repairs—Labor	1.20
Material	1.15
Depreciation	1.70
Taxes	0.40
Insurance	0.20
Manufacturing burden	0.20
Total conversion cost	10.72
Fuel—Coal	29.50
Wood	
Oil	
Electric steam	
Total fuel cost	29.50
Total cost per 1000 pounds, delivered from and at 212°F.	40.22

STEAM UTILIZATION

272. Distribution Methods.—It is customary in modern mills of the paper industry to consider the steam plant as a separate department that generates a product chargeable to the consuming departments at actual cost of production. Some plants use a standard cost unit to evaluate the steam, thereby allowing the steam plant to show a profit or loss, depending on the efficiency of operation. All the steam mains to the various departments, such as the paper mill, chemical-pulp plant, power plant, etc., are adequately equipped with steam-flow meters, and the exact amount of steam used is calculated. Measured distribution has been found to be an advantage, especially in the paper mill and in the digester room of the chemical-pulp plant, where each machine or digester is equipped with an individual meter. Moreover, such an arrangement provides a check between the master meter of each department and the individual meters to the various units.

The measurement of electric power has always been accepted as the best way of determining the consumption. During the past few years, the same principle has been adopted by various mills with regard to steam, and its measurement is considered a necessity in the operation of a pulp and paper mill; it enables the executives to keep a closer check on operating conditions, and it provides the accounting department with the proper figures on which to base the costs. It is true that no metering or measuring equipment is perfect, but a group of steam-flow meters kept in good mechanical condition, and currently tested and inspected, should show results that are accurate within 2% under normal conditions.

273. Distribution Systems.—The flow of steam to the various departments will vary according to the physical layout of the plant, grade of paper and pulp made, and the type of prime mover used to drive the paper machines and other equipment. The steam and power distribution systems may be broadly classified as:

(1) Mechanical drive:

Machines are driven by steam engine or steam turbine, and the exhaust steam is used to dry paper.

(2) Electrical drive:

(*a*) Direct. The drive may be either a single motor or sectionalized, and the alternating-current is changed to direct-current by a motor-generator set. Live steam is used to dry the paper, and is reduced to the required pressure by a valve.

(*b*) Turbo-generator set. The direct-current is derived from a turbo-generator on each machine, and the exhaust steam is used to dry paper.

(*c*) Extraction turbine. All steam used in the plant passes through the turbine, which functions as a reducing valve and a producer of electric power. Steam is used at low pressures (approximately, 25 pounds) for drying paper and heating. Where steam is required for chemical pulp, the steam is extracted at an intermediate pressure (approximately 125 pounds) as well as the low pressure.

274. Steam Balance.—By **steam balance** is meant the using of all the steam in such a manner as to get the most heat units

out of it. In pulp and paper mills, steam is used for many purposes and at various pressures; hence, if steam be generated at high pressure (and, perhaps, superheated), it should be used in a high-pressure apparatus, as an engine or turbine; then if steam at a lower pressure is wanted somewhere else, the exhaust from the engine or turbine, which may be at a comparatively high pressure for exhaust steam, may be used in some other piece of apparatus, from which it may again be exhausted at a lower pressure, and the last exhaust may be used for drying, heating feed water, or for other process work. The better the arrangements for accomplishing these results the better the heat balance.

When the exhaust steam from a paper-machine steam engine or turbine goes to the dryers, live steam is supplied as required in order to create a drying balance. The extraction or reducing turbine automatically provides a steam balance, because all the steam that passes through it is necessary for process work. Hence, this arrangement is the most economical, especially where steam at high pressures and superheat is used. It is possible to apply any one of the steam- and power-distribution systems to a mill making any grade of pulp or paper, but it is essential to get the proper steam balance for economical operation.

275. Steam-Distribution Diagrams.—The following diagrammatic sketches of steam distribution systems illustrate several that are widely used, together with typical metering equipment. The legends make them self-interpretative.

Exhaust and Live-steam Balance

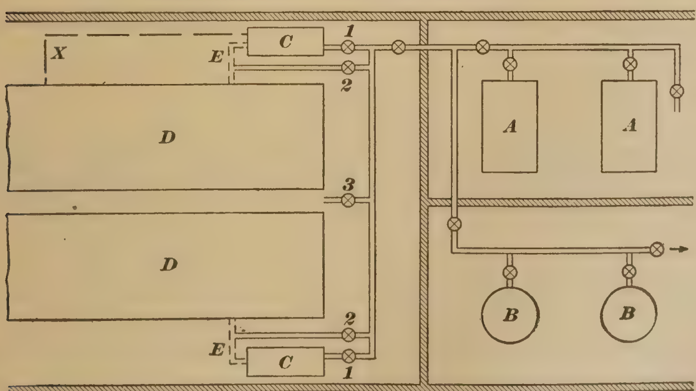

Fig. 60.

A, boilers; *B*, chemical-pulp digesters, old paper, or rag cookers; *C*, paper-machine prime mover; *D*, paper machine; *E*, exhaust line; *X*, direct-current line, when turbo-generator is used; 1, meter on steam line to prime mover; 2, live-steam meter on makeup system; 3, meter on steam line to ventilating fans, heating, etc., in paper mill.

STEAM BALANCE BY EXTRACTION METHOD

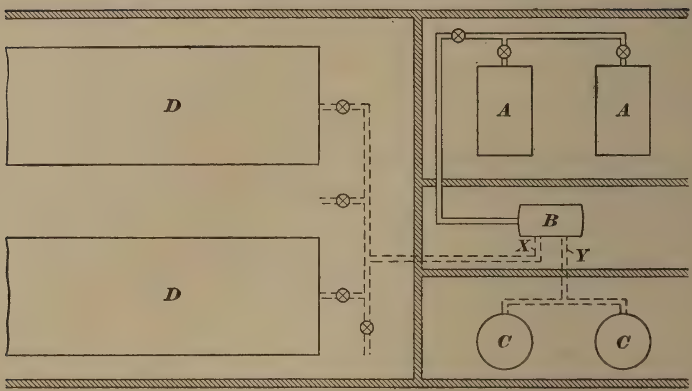

FIG. 61.

A, boilers (approximately 400 pounds pressure and 200° superheat; *B*, extraction turbine, two-stage (might be a one-stage turbine, or equipped with a condenser); *C*, pulp digesters, rags or old-paper cookers; *D* paper machines; *X*, low-pressure line (approximately 25 pounds, for paper drying, heating, and miscellaneous uses); *Y*, intermediate-pressure line (approximately 125 pounds, for cooking chemical pulp, old papers, rags, etc., further reduced if necessary.

TYPICAL STEAM DISTRIBUTION SYSTEM, USING EXTRACTION TURBINE

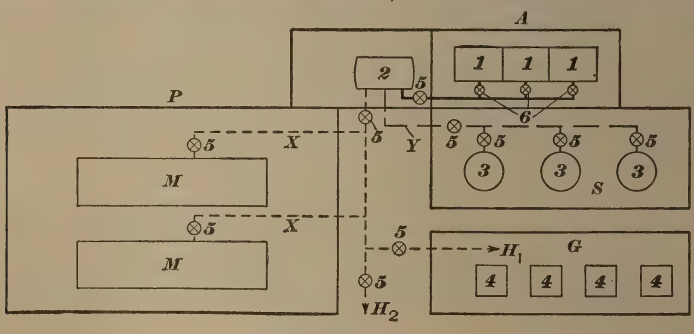

FIG. 62.

A, steam plant; *S*, sulphite mill; *G*, groundwood mill; *P*, paper mill; H_1, heating; H_2, heating and miscellaneous; *X*, low-pressure line (25 pounds); *Y*, intermediate-pressure line (125 pounds); *M*, paper machines; 1, 1000-horsepower boilers (400 pounds gauge pressure); 2, 2500-kilowatt extraction turbine (two-stages, 125 pounds and 25 pounds); 3, digesters; 4, grinders; 5, steam-flow meters; 6, boiler meters.

276. Steam Requirements.—The steam demand varies in every mill because of the different equipment used, and because of the variation in the production of pulp and paper. Newsprint mills are perhaps the best for purposes of comparison, and the following table indicates the average estimated steam requirements of a 200-ton balanced newsprint mill:

Consuming department	Product made per day (tons)	Total steam per day (pounds) (F. and A. 212°)	Pounds of steam per ton of product	Per cent used of total steam generated
Paper mill	200	1,940,000	9700	75
Sulphite mill	50	390,000	7800	15
Groundwood mill	150	25,000	....	1
Miscellaneous heating, etc.	...	130,000	....	5
Boiler-house usage	...	110,000	....	4
Total	...	2,595,000	....	100

RECLAIMING HEAT, AND PREVENTION OF HEAT LOSSES

277. Reclamation of Heat.—A modern boiler house is well equipped with economizers or other apparatus for reclaiming the heat in the stack gases. The next largest source of heat loss is

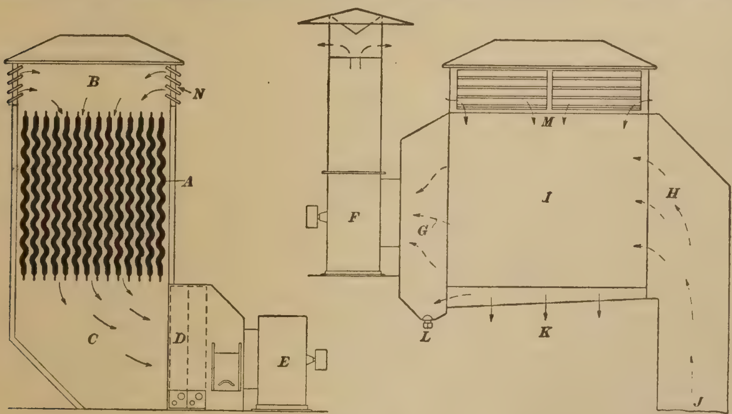

FIG. 63.

A, heat-transfer elements; *B*, cold air to be heated; *C*, warm air; *D*, auxiliary heating coils; *E*, fan supply to machine room; *F*, exhaust fan; *G*, cooled vapor; *H*, hot vapor; *I*, economizer; *J*, connection to machine hood; *K*, warm air; *L*, drain for condensed vapor; *M*, cold air to economizer; *N*, fresh air, which is drawn down between the heat-transfer elements *A*, through which the vapor from the drying paper is drawn horizontally. Provision is made to draw off any condensate that may form, and to add this warm water to the boiler feed.

in the water evaporated by the drying of the paper, which is given off as vapor.

The **vapor economizer,** adopted by many paper mills during the past few years, reclaims much of the latent heat in the vapor given off by the dryers; this is accomplished by using the heat of the air going from the paper machines (which is of high relative humidity) to heat the air being drawn into the machine room for

ventilating purposes. This type of economizer for paper machines, Fig. 63, has proved very satisfactory, especially in winter, where mills are located in cold climates. The recovery of heat depends on the difference in temperatures between the incoming air and the outgoing vapors; the principle is fully explained in Part 3 of this Section. In a number of instances where installations of this kind have been made under favorable conditions, the equipment has paid for itself in 3 or 4 years.

Another method of reclaiming the heat in the vapor is by means of a *water-spray system.* This has not been generally adopted, since it requires an additional heat interchange, with its resultant losses, and the large amount of hot water that is produced cannot be utilized in the average paper mill.

278. Prevention of Heat Losses.—Air is commonly used as a carrier of heat in a paper mill, both for ventilation in the machine room and general heating throughout the mill. Inadequate or poorly designed heating and ventilating systems result in considerable loss.

The *central heating and ventilating system,* with the correct design of ducts, is recognized to be the most efficient method of handling the heating problem in the machine room. In connection with the ventilating system, a standard or special *hood* is the best practice, and it is considered essential in a well-ventilated machine room. The hood over the paper machine serves as a medium to concentrate the vapors arising from the drying paper so that they can be removed at high humidities, thus minimizing the losses due to warm air leaving the machine-room exhaust ducts. Moreover, the hood keeps the vapor from being distributed throughout the machine room, and it reduces the danger of having moisture collect on the under side of the machine-room roof. It also simplifies the ventilation problem, and it reduces the amount of air required to keep the machine room in good condition.

The unit heater has been tried out in the machine room, but it has not proved so satisfactory as the central heating and ventilating system equipped with ducts. The unit heater is better adapted to the beater room, finishing room, and other parts of the mill where the relative humidity of the air is comparatively low, and the removal of moisture-laden air is not a problem.

A recent development, which is virtually a *new method of ventilation,* is the use of high-pressure air in the dryer part. This

speeds up the rate of drying, since it eliminates to a large degree dead vapor pockets between the dryer canvas and dryer rolls, because the air is forced across the dryer rolls at right angles to the movement of the paper.

279. Condensate Removal System.—Nearly all the steam used by the paper machine to dry paper condenses in the dryers when giving up its latent heat. There are a number of systems available for removing this water of condensation, and all, no doubt, have their merits. The primary function of the condensate-removal system is to keep the dryer free from water and air (both are good non-conductors of heat), and to return the condensate to the boiler house. The speed of circulation, pressures used, and other features in connection with a condensate-removal system, are only secondary, since actual losses can occur only when there is a physical waste of steam or hot water, or if the dryer does not efficiently transfer heat to the paper. There are three major principles utilized to force or discharge condensate from the dryer: (1) by siphonic action; (2) by mechanical force (dippers, etc.); (3) by a difference in steam pressure between the dryer and the condensate header.

Some condensate-removal systems are equipped with individual air-venting traps, while in others, the dryer part is divided into two or three sections. In general, the simpler and less complicated the drying system the more effectively will it function; moreover, if clearly understood by the operator, it can be more easily kept in proper operating condition.

280. Losses by Radiation from Pipes.—Steam engineers have long recognized the value of properly insulating all steam and hot-water piping systems. This is absolutely essential for high-pressure steam lines carrying superheated steam to turbines. The heat losses due to inadequate insulation of steam piping are well illustrated by the chart, Fig. 64. This chart was compiled from extensive experimental data developed by the Mellon Institute and published in pamphlet form. From this chart, it is seen that a 4-inch pipe carrying steam at 120 pounds gauge pressure, such as might be carried on a digester steam line, would lose 104,000,000 B.t.u. per month. If the heating value of coal be taken as 13,000 B.t.u., this is equivalent to a coal loss of 8000 pounds, or 4 tons.

281. Heat Losses through Roofs.—The proper insulation of roofs is also important, especially in the machine room, where the inside air is heavily laden with vapor and the outside air may be at a very low temperature, particularly during the winter months. Roofs have been very satisfactorily insulated by using a combination of wood and such other insulating material as cork board, balsam wool, celotex, etc. Some plants have been constructed by using a hollow concrete slab together with special insulation.

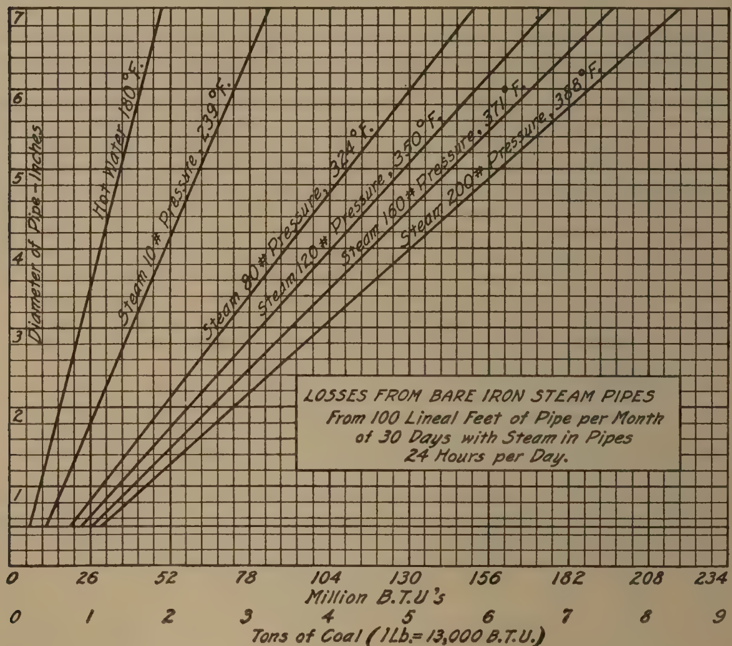

Fig. 64.

Perhaps the most widely used material is gypsum, which is semipermanent in character when not subjected to excessive moisture conditions. Concrete is a very poor insulator of heat; but when it is used with cork board, celotex, or other like material, it has proved to be very satisfactory, and is about the same as gypsum as an insulating material; however, it has the disadvantage of disintegrating under the warm, moist conditions that usually obtain in paper-machine rooms. Insulating material assists in prolonging the life of a wood-deck roof; and if redwood, cedar, or a treated wood be used, such a roof is nearly as good under normal conditions as one made of the best of any other material.

It is also necessary to prevent loss of heat through windows. Hence, it is best to have double windows in cold climates and to prevent, or minimize, drafts by having tightly fitting windows and door frames.

282. Steam Leaks.—The large number of steam mains and pipes in the average paper mill multiplies the difficulty of eliminating losses due to steam, water, and air leakage and wastage. The great importance of carefully watching the ordinary steam, water, and air piping, valves, etc., in a mill is emphasized in the following table, which shows the loss in volume and value through openings of various diameters:

STEAM, AIR, AND WATER LEAKS

Size of opening, inches	Steam		Air		Water	
	1000 pounds wasted per year at 100-pound pressure	Total loss per year in dollars at 40 cents per 1000 pounds	1000 cubic feet wasted per year at 100 pounds pressure	Total loss per year in dollars at 8 cents per 100 cubic feet	1000 gallons wasted per year at 40 pounds pressure	Total loss per year in dollars at 12 cents per 1000 gallons
$\frac{3}{8}$	5520	2208.00	119,750	9580.00	8309	997.18
$\frac{1}{4}$	2436	974.00	53,395	4271.60	3692	443.04
$\frac{1}{8}$	606	242.40	13,375	1070.00	924	110.88
$\frac{1}{16}$	153	61.20	3,354	268.32	230	27.60

The magnitude of such losses in a large plant often justifies the appointment of a special man to investigate various steam losses, recommend corrections in the steam distribution system, and to test all traps, valves, etc., around the plant. The annual savings are usually large enough to warrant giving considerable attention to this source of waste.

283. Miscellaneous.—It is the practice of many mills to use steam in the beaters and for heating, for hot water, and for other miscellaneous purposes. This form of steam consumption has been the outgrowth of old systems and methods; and though steam is really necessary at times, much more is used than is actually required. All forms of steam and power consumption should be given very complete study in every paper mill, and it should be the duty of the steam engineer fully to conserve and utilize all available heat units produced by the steam plant.

STEAM-POWER LITERATURE

Steam Power Plant Engineering: Gebhardt.
Steam Power: Hirshfield and Ulbright.
Elements of Steam and Gas Power Engineering: Potter and Calderwood.
Engineering of Power Plants: Fernald and Orrock.
Combustion in the Power Plant: Marsh.
Boiler-Plant Testing: Brownell.
Steam: Babcock and Wilcox.
Steam Boiler Economy: Kent.
Elements of Steam Engineering: Sprangler, Green, and Marshall.
The Power Plant: Myers.
Modern Practice in Heat Engines: Petrie.
Reports of National Electric Light Association.
Reports of the Joint Feedwater Committee: American Society of Mechanical Engineers.

GENERAL MILL EQUIPMENT

(PART 5)

EXAMINATION QUESTIONS

(1) (*a*) Explain why steam is used so extensively, and (*b*) mention some of its uses in pulp and paper mills.

(2) Define: (*a*) sensible heat; (*b*) latent heat; (*c*) specific heat; (*d*) combustion.

(3) The analysis of a certain coal was as follows: carbon, 82.87%; hydrogen, 2.38%; oxygen, 6.81%; sulphur, 0.69%; calculate the calorific value of the coal. Ans. 13,075 B.t.u.

(4) Define: (*a*) dry saturated steam; (*b*) wet steam; (*c*) superheated steam; (*d*) specific volume. (*e*) Why does the specific volume of steam change with the pressure?

(5) What is the horsepower of a boiler that evaporates 3790 pounds of dry and saturated steam per hour at 175 pounds gauge pressure, the temperature of the feed water being 58°F.? The total heat of 1 pound of steam at this pressure is 1197.3 B.t.u. Ans. 132.54 – h.p.

(6) What special points should be considered when selecting coal for a boiler installation for a paper mill?

(7) (*a*) What is a common method of rating a boiler? (*b*) If a boiler evaporated 11 pounds of water per hour per square foot of heating surface, what would be its rating?

(8) Discuss economizers, air preheaters, and superheaters. What do they do and how? In what way do they save fuel?

(9) In what way is incomplete combustion related to the furnace volume?

(10) What is a steam accumulator, and what does it do?

(11) Mention some of the advantages of mechanical stokers, and describe one type.

(12) (*a*) What is soot? (*b*) Why is it a detriment? (*c*) How can it be removed?

(13) Why is it important to measure: (*a*) the coal? (*b*) the water? (*c*) the steam? (*d*) What influence has the amount of CO_2 in the flue gases on furnace economy?

(14) Sketch the steam distribution system of a mill (preferably, the mill in which you are employed) and criticize it.

(15) State in your own words what you understand by steam balance.

(16) (*a*) Mention some of the sources of heat losses as applied to the plant in which you work. (*b*) What would you suggest in the way of reclaiming and saving heat? (*c*) Would your suggestions pay if adopted, and why?

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NOTE.—The paging begins with 1 in each Section, and each Section has its number printed on the inside edge of the headline of each page. To find a reference, as "Acid dyestuffs, §5, p7," glance through the volume until a headline containing §5 is found, and then find page 7.

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